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Ministry of Environment
ASSESSMENT AND PLANNING DIVISION

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BIOPHYSICAL RESOURCES OF THE EAST KOOTENAY AREA:

TERRAIN

J. M. Ryder
TERRESTRIAL STUDIES BRANCH

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PREFACE

This report is one of a series of Assessment and Planning Division (APD)[1] bulletins that describe and analyse the biophysical resources of the East Kootenay area. Individual bulletins focus on terrain, soils, climate, vegetation, wildlife, aquatics, and outdoor recreation, but are closely interrelated and rely on cross-referencing rather than duplication of material. A set of base data maps at a scale of 1:50 000 is also available for each discipline.

The East Kootenay study was initiated in 1975 in response to increasing pressure on land resources and the development of land use conflicts. Forestry, mining, ranching, farming and tourism are all major contributors to the economic well-being of the region. General population growth and maintenance of these industries requires that land be allocated for urban and industrial expansion and transportation corridors, and yet at the same time, areas be preserved for wildlife and recreational purposes.

The data, analyses, and interpretations that are contained within the East Kootenay bulletin and map series will assist in the development and implementation of a rational resource management policy. In addition, information is presented here that will increase systematic knowledge of the physical and biological components of land and water systems.

It is anticipated that careful utilization of this data base will ultimately result in the maintenance of a high quality environment in this part of British Columbia.

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[1] Formerly Resource Analysis Branch, Ministry of Environment

ACKNOWLEDGEMENTS

Terrain mapping in the East Kootenay region was carried out by Val Hignett, Mike Fenger, Roxy Beale Kuurne, Terry Rollerson, Marilynn Rode Hunter, Alan Pattison, Bruce Thomson, and the writer. Lesley Anderton of Selkirk College, Castlegar, worked with Terrestrial Studies Branch (formerly Resource Analysis Branch) staff in the Flathead area. Terrain and soils mapping was coordinated by Larry Lacelle. Both the terrain mapping scheme in general, and this report in particular, have benefitted from the innumerable discussions that arose amongst this group of co-workers.

The writer wishes to thank John Clague of the Geological Survey of Canada, Vancouver, for review of this report.

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Chapter One

Chapter One

INTRODUCTION

This report describes the nature and distribution of surficial materials, landforms and present day geological processes in the East Kootenay region. The term "terrain" is used here to refer collectively to these aspects of the physical landscape. Bedrock geology is included in this report only in so far as it influences terrain characteristics.

Surficial materials are those sediments of relatively young geological age that underlie much of the land surface, such as gravel, sand and (glacial) till*. The physical properties of these materials, together with ground surface configuration, influence conditions such as drainage, soil development, slope stability, and bearing strength*. Geological processes that are active at the present time range from violent and potentially destructive events, such as avalanches and landslides, to relatively innocuous effects such as weathering* and soil creep*. Many of the former constitute potential hazards to humans and to some forms of land use. Thus the nature of the terrain exerts a physical control upon the way in which land can be used (or cannot be used) for urban, agricultural, industrial or other purposes. A comprehensive terrain map is an essential part of the basic information needed for land-use planning and decision making.

The region covered by this report extends from the International Boundary at 49°N, northward for 240 km to 51° 07' N near Vermilion Pass on the Continental Divide. It extends eastward from 116° W to the Alberta boundary along the Continental Divide, a maximum distance of 140 km (Figure 1.1). The area includes approximately 19 400 km^2.

Terrain mapping was carried out in the field by Terrestrial Studies Branch personnel during the summers of 1975 and 1976. Maps were prepared at a scale of 1:50 000. The method of terrain mapping that was employed is described and illustrated in Chapter Three. Maps may be obtained individually from the Assessment and Planning Division[1]. This report is accompanied by a generalized terrain map (in pocket) at a scale of 1:250 000 which was compiled by simplification of the original terrain maps.

---

* See Glossary (Appendix A) for definition. Words defined in the Glossary are indicated where they appear for the first time in each Chapter.

[1] The Map Library, Assessment and Planning Division, Ministry of Environment, Parliament Buildings, Victoria, B.C., V8V 1X4

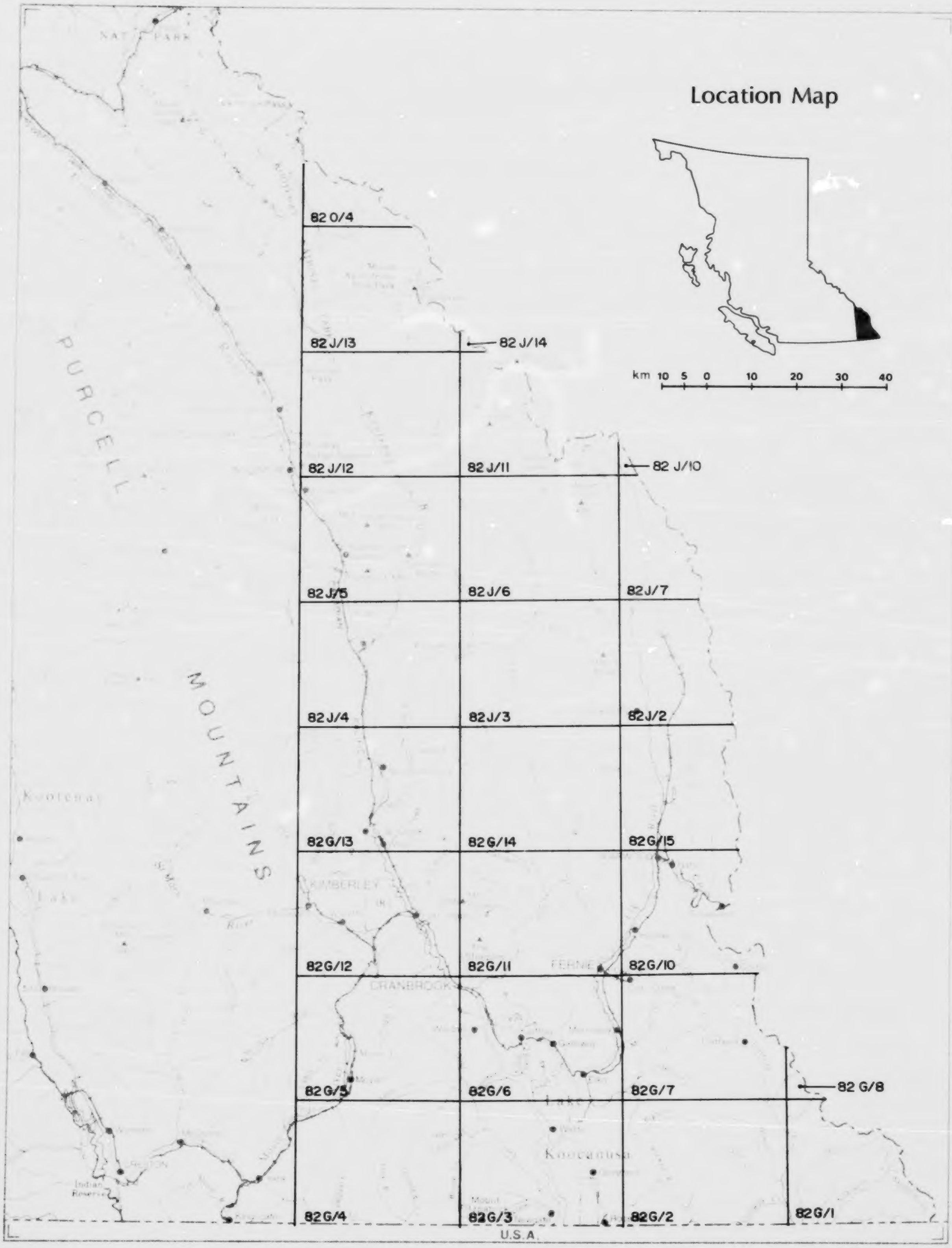
Location Map
km 10 5 0 10 20 30 40
NAT. PARK
82 O/4
82 J/13
82 J/14
82 J/12
82 J/11
82 J/10
82 J/5
82 J/6
82 J/7
82 J/4
82 J/3
82 J/2
82 G/13
82 G/14
82 G/15
82 G/12
82 G/11
82 G/10
82 G/5
82 G/6
82 G/7
82 G/8
82 G/4
82 G/3
82 G/2
82 G/1
PURCELL
MOUNTAINS
Kootenay
Lake
KIMBERLEY
CRANBROOK
FERNIE
Lake
Koocanusa
Indian Reserve
U.S.A.

Figure 1.1 Location map (with 1:50 000 NTS grid).

An overview of most of the East Kootenay area is provided by the satellite image shown in Plate 1.1. The broad valley in the centre of the area, the Rocky Mountain Trench (or the Trench), separates the Purcell Mountains to the west from the Rocky Mountains (or the Rockies) to the east. The contrasting geology and landforms of these areas are described in Chapter Two. The central and southern parts of the Trench are drained by Kootenay River which flows southward into Lake Koocanusa, the Libby Dam reservoir. The lakes further north (Columbia and Windermere Lakes), are the headwaters of northward flowing Columbia River. Patterns of agriculture and settlement are faintly visible on the floor of the Trench; the towns Kimberley, Cranbrook and Invermere appear as irregular, pale grey patches. Some recently logged areas in the mountains can also be distinguished. About 90% of the area shown here is covered by surficial materials such as till, sand and gravel, and weathered rock debris (colluvium*). These sediments vary in thickness from a few centimetres on some mountain slopes to hundreds of metres beneath the floor of the Rocky Mountain Trench. Mountain tops and ridges of bare rock dominate the landscape out of all proportion to the meagre 10% of the area that they occupy.

The general characteristics of geology and terrain in the East Kootenay region are reviewed in Chapter Two. This information provides context for more detailed descriptions of surficial materials that follow in Chapters Four to Eight. Geological hazards are discussed in the final chapter.

Descriptions of surficial materials in parts of the East Kootenay region have been previously given in soils reports (Kelley and Sprout, 1956; Kelley and Holland, 1961) and a regional report (Runka, 1969). Several aspects of the Quaternary geology of the Rocky Mountain Trench were investigated by J.J. Clague (1973, 1975). Information from these and other sources mentioned in the text has been incorporated into the following account.

1.1 HOW TO USE THIS REPORT

This report has been written primarily for the non-geologist. Technical terms are avoided or defined in the Glossary (Appendix A). It is anticipated that readers will include planners, biologists, engineers, foresters, pedologists, agriculturists, students, and other people seeking miscellaneous information. The report should also be examined by geologists who may use the associated terrain maps as a starting point for more detailed surveys or interpretations, since it includes information that is not portrayed on those maps.

Plate 1.1 Most of the East Kootenay region is shown on this Landsat image. The chief physiographic features are clearly visible, and some landuse patterns can be distinguished (see text). Landsat 1 image E-10794-17572-6 for centre 46-25, 25 September, 1974. Copyright: Canada Centre for Remote Sensing.

Such a variety of readers cannot all be expected to utilize this report in a similar manner, or read it from cover to cover! Accordingly, the following recommendations are made:

1. People whose work regularly involves them with terrain conditions in the East Kootenay region would probably benefit from reading the whole report. This would, hopefully, be useful also from an educational point of view. The general geological knowledge gained from this process would be applicable in almost any part of British Columbia.
2. A general overview of the region, or any large part of the region, can be obtained by reading the physiographic descriptions contained in Chapter Two.
3. Readers intending to utilize the 1:50 000 scale terrain maps who are not familiar with the terrain mapping scheme that is used in British Columbia, should first read Chapter Three, particularly sections 3.1, 3.2, and 3.4.
4. For information regarding the characteristics of terrain within a specific area of interest, readers should first examine the appropriate terrain map and note the terrain unit symbols. Then the sections of the report that describe these specific terrain types (in Chapters Four to Eight) can be consulted (Note that all commonly applied terrain unit symbols (eg. gFt, Mb, Cv) are shown in the Table of Contents in order to facilitate use of the report). The first and second sections of each Chapter should also be read at this stage, since they contain descriptions of material properties and general land use considerations. Thus, for example, a "gFt" terrain unit is described in section 5.3.2 (see Table of Contents), and information about fluvial materials in general is given in sections 5.1 and 5.2.
5. Specific interpretations of terrain and soil conditions for potential land uses such as septic tank drainage fields, foundations for low rise dwellings, local road and street subgrade, and excavations, are given in the APD bulletin "Biophysical Resources of the East Kootenay Area: Soils" (which will be referred to as the "East Kootenay soils bulletin" in the remainder of this report). A reader seeking such information should consult the appropriate soils map[1], note the soil association components that are present in the area of interest, and then refer to the soil association description in the soils bulletin. Alternatively, the correlation table (Appendix E of this report) can be used for a rough conversion of terrain units to soil association components.

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[1] Available from the Map Library, Assessment and Planning Division, Ministry of Environment, Parliament Buildings, Victoria, B.C., V8V 1X4

6. The information contained in this report and on the accompanying terrain maps should not be applied to site specific problems such as bridge locations or subdivision layouts. It may be used, however, to identify potentially troublesome sites where detailed site specific studies are needed.

Chapter Two

Chapter Two

PHYSIOGRAPHY

2.1 INTRODUCTION

This chapter provides an overview of the general characteristics of terrain in the East Kootenay region. It includes descriptions of the major mountain ranges, bedrock types, and the origin and distribution of surficial materials.

The sediments which now constitute bedrock in the East Kootenay region accumulated over a time span of about one billion years (see legend to Figure 2.1). Tectonic* uplift and deformation occurred chiefly between 100 and 50 million years ago, although movement along faults has taken place more recently. Landforms such as cirques* and glacial troughs are much younger. They were eroded by glaciers during the last few hundred thousand years. Depositional landforms such as moraines and alluvial fans, and most surficial materials that are described in this report, are younger still. They formed during the past thirty thousand years either during the most recent glacial period (Fraser Glaciation, Armstrong et al., 1965) or during post-glacial time. The recent geological history of the East Kootenay region is described in more detail below.

2.2 QUATERNARY HISTORY AND DEVELOPMENT OF LANDFORMS

The Quaternary Period is the most recent episode of geological history. It was characterized by climate fluctuations which gave rise to alternating glacial and non-glacial conditions over large areas of the earth during the past two or three million years. In the East Kootenay region there is geological evidence of several glaciations of varying magnitude. Deposits of the three most recent episodes (three phases of Fraser Glaciation) are present in the southern part of the Rocky Mountain Trench (Clague, 1975). Evidence of earlier glaciations has been found in adjacent parts of British Columbia, Alberta and the United States (cf. Fulton, 1971; Stalker and Harrison, 1977; Richmond, 1965), and these would also have affected the East Kootenay region (Table 2.1). The most recent events are of greatest significance however, since they are responsible for the present day character and distribution of landforms and surficial materials.

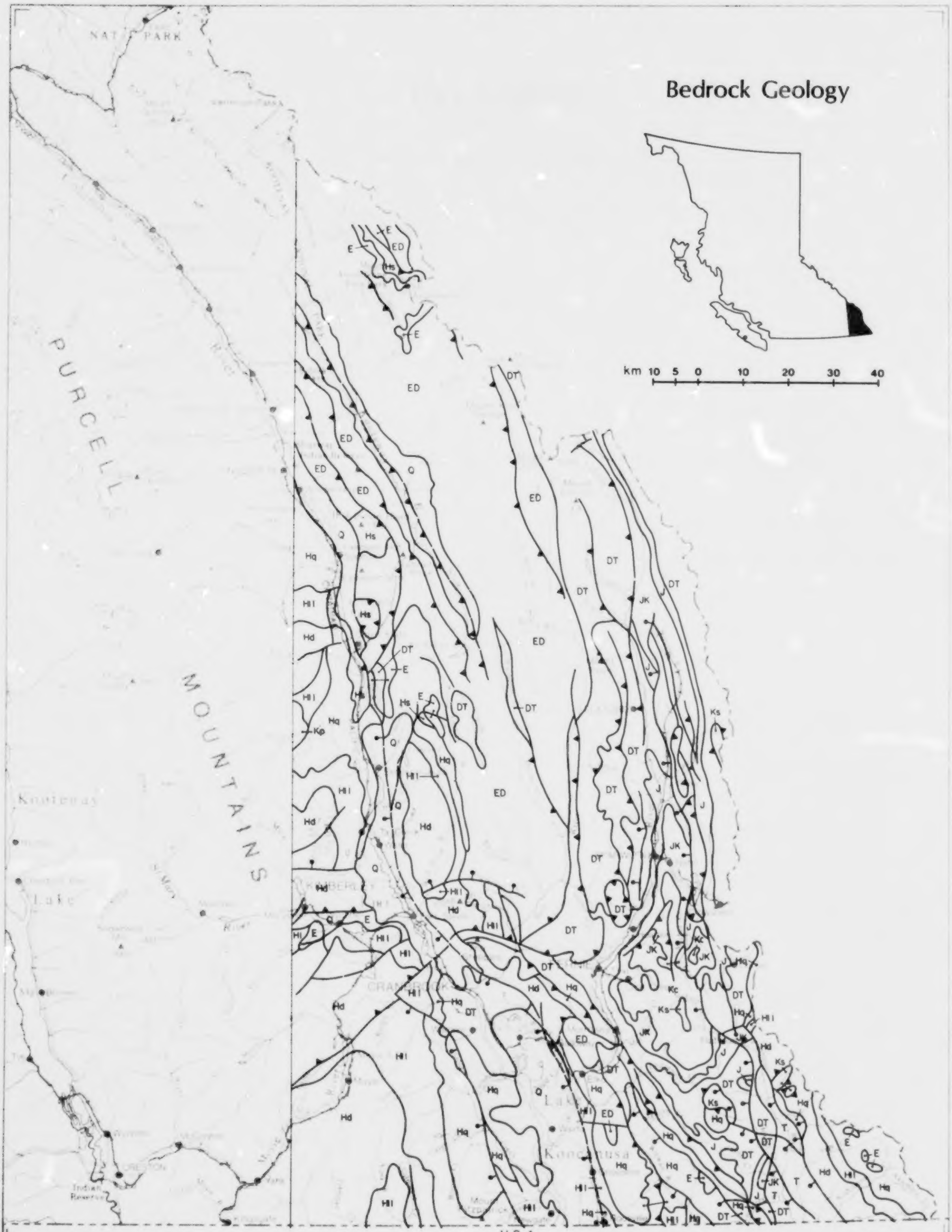

Bedrock Geology
km 10 5 0 10 20 30 40
NAT. PARK
PURCELL
MOUNTAINS
Kootenay
Lake
KIMBERLEY
CRANBROOK
Koocanusa
CRESTON
Indian Reserve
U.S.A.
ED
E
Hs
DT
Q
Hq
Hl
Hd
Kp
JK
J
Ks
Kc
T

Figure 2.1 Bedrock geology (from Okulitch and Woodsworth, no date).

LEGEND

QUATERNARY AND RECENT (present to 2.5 million yr B.P.)

Q	Glacial and post-glacial deposits

TERTIARY (2.5 to 65 m.y.)

T	Sandstone, conglomerate

CRETACEOUS (65 to 136 m.y.)

Ks	Sandstone, shale
Kg	Quartz monzonito, granite
Kc	Sandstone, shale, coal conglomerate

JURASSIC-CRETACEOUS (190 to 65 m.y.)

JK	Sandstone, siltstone, shale, coal conglomerate (Kootenay Formation)

JURASSIC (136 to 190 m.y.)

J	Shale, siltstone, sandstone, limestone (Fernie Group)

DEVONIAN to TRIASSIC (395 to 190 m.y.)

DT	Limestone, shale, dolomite, sandstone

CAMBRIAN to DEVONIAN (570 to 345 m.y.)

ЄD	Limestone, shale, dolomite

CAMBRIAN (570 to 500 m.y.)

Є	Quartzite, limestone, phyllite, argillite

PROTEROZOIC (>570 m.y.)

Hs	Sandstone, conglomerate, limestone
Hq	Quartzite, argillite, dolomite, siltstone
Hl	Limestone, argillite, quartzite, andesitebreccia, tuff
Hc	Limestone, dolomite, quartzite, argillite

▲▲▲▲▲	Thrust faults
• • • •	Normal faults

TABLE 2.1:

GLACIAL SEQUENCES FOR EAST KOOTENAY REGION (SOUTHERN ROCKY MOUNTAIN TRENCH) AND ADJACENT AREAS. NO CORRELATION OF SEQUENCES IS INTENDED BEYOND THE LIMIT OF ABSOLUTE DATING

Years B.P.	South Central British Columbia (Fulton & Smith, 1978)	Southern Rocky Mountain Trench (Clague, 1975)	Southeast Alberta (Stalker & Harrison, 1977)	Rocky Mountains (USA) (Richmond, 1965)
0-	RECENT (postglacial sediments)	(postglacial sediments)		
10 000-	FRASER GLACIATION (Kamloops Lake Drift)	Younger drift { **glacial stade** **interstade** **glacial stade** Interdrift sediments **Older drift**	WATERTON IV GLACIATION	PINEDALE GLACIATION { Late stade Interstade Middle stade Interstade Early stade
20 000-				
30 000-	OLYMPIA INTERGLACIATION (Bessette Sediments)	Interglacial sediments	Interglaciation	INTERGLACIATION
40 000- limit of absolute dating	OKANAGAN CENTRE GLACIATION (Okanagan Centre Drift)		WATERTON III, II GLACIATION	BULL LAKE GLACIATION { Late stade (two glacial episodes) Nonglacial interval Early stade
	WESTWOLD INTERGLACIATION (Westwold Sediments)	▨ - phases of Fraser Glaciation in the southern Rocky Mountain Trench	earlier glaciations and interglaciations	INTERGLACIATION earlier glaciations and interglaciations

The sequence of events that occurred during Fraser Glaciation has been reconstructed by Clague (1973, 1975) and much of the following description is condensed from his accounts. At the onset of the glaciation, ice accumulation commenced in cirques at high elevations in the Rocky and Purcell Mountains. These small glaciers gradually expanded and merged into a system of valley glaciers. Eventually, by about 17 000 years B.P. (Clague et al., 1980), large southerly flowing ice streams developed in the Rocky Mountain Trench and the Flathead Valley. The Trench glacier originated in mountains well to the north of the study area, but was augmented by local glaciers. Eventually, all major valleys were occupied by ice that was more than 1000 m thick. Glaciers coalesced across ridge crests so that only high peaks protruded. The trunk glacier reached a thickness of about 1500 m in the Trench at the International Boundary (Daly, 1912). It extended into Montana, and terminal moraines* were constructed near Flathead Lake at Polson and Kalispell, 130 km and 60 km respectively south of the Canadian border.

During ice retreat at the end of the early phase of Fraser Glaciation, meltwater streams* deposited sands and gravels, while silt and sand accumulated in lakes on the Trench floor. Similar materials were deposited during the interval between the second and third phases, but their characteristics suggest that this was of very short duration and masses of stagnant ice may have persisted in the centre of the Trench.

The final deglaciation commenced about 15 000 years ago. As the glacier snout retreated from terminal moraines in Montana, valley glaciers in British Columbia gradually thinned, and overridden ridges and summits emerged through the lowering ice surface. Glaciers in tributary valleys melted more rapidly than the Trench glacier, which was still supplied by ice from mountains further north. Some valleys became open whilst downstream areas were still occupied by ice, so that ice-dammed lakes were formed. For example, ice in Elk Valley and lower Michel Creek impounded a lake in the valley between Loop and Crowsnest Pass (Harrison, 1974). As this ice tongue gradually receded, the lake expanded until it occupied a large part of Elk Valley, although lake levels fell as lower outlets became ice-free. At various stages of deglaciation, parts of the valleys of Wigwam, Bull, White, and Lussier Rivers and Gold, Teepee, and Skookumchuck Creeks and many others were temporarily occupied by lakes (Chapter Six).

Eventually a large ice tongue remained in the Trench although subsidiary glaciers had receded far up their valleys (Figure 2.2). The Trench glacier was not stagnant but continued to flow

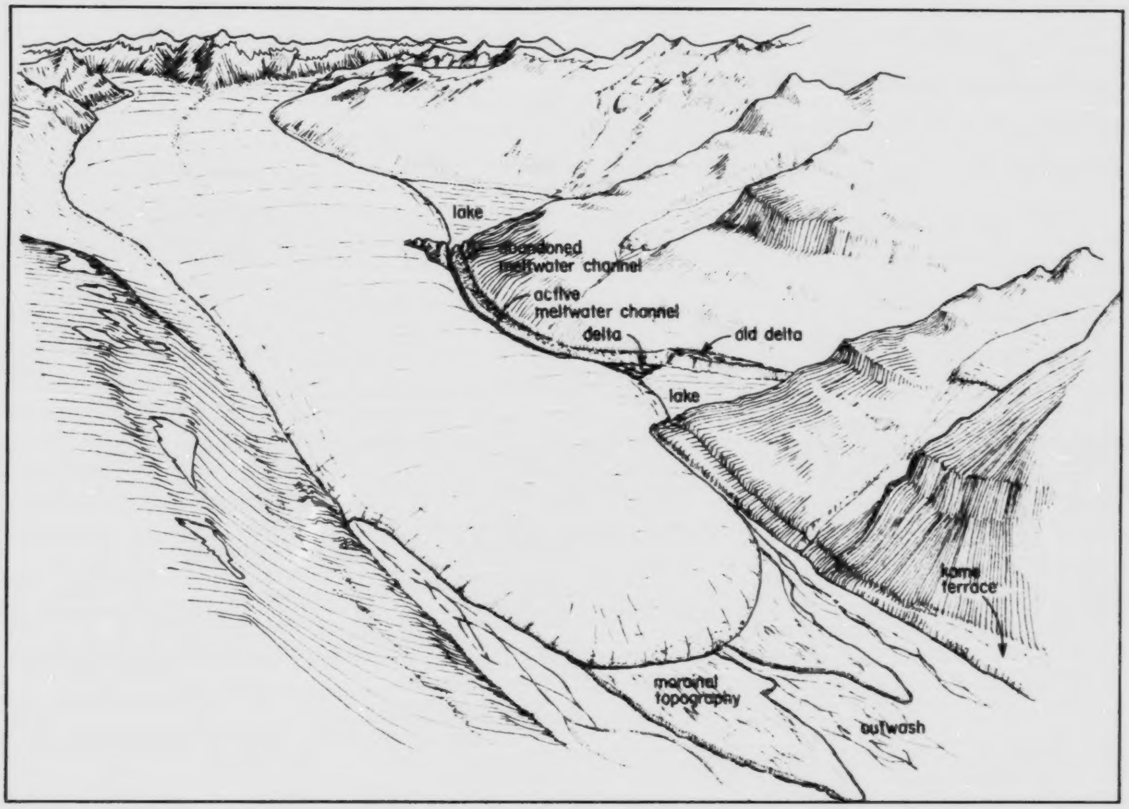

lake
abandoned meltwater channel
active meltwater channel
delta
old delta
lake
kame terrace
morainal topography
outwash

Figure 2.2 Receding glacier in Rocky Mountain Trench and associated landforms.

southward and bulged into the mouths of valleys such as St. Mary River, Elk River, and Moyie Lake. Drainage from these and other tributaries was impounded by the ice and deflected southward along ice-marginal meltwater channels (section 5.3.4). As the ice surface downwasted, channels and lake outlets were formed at successively lower elevations. Some streams such as Skookumchuck Creek and Elk River still swing abruptly south as they enter the Trench to follow courses established by glacial diversion. Lakes occupied the lower parts of St. Mary, Elk, Wigwam and other valleys at this time. In some places gravels and sands, which were carried by tributary or meltwater streams, were deposited against the ice margin to form kames* and kame terraces* (section 5.3.5).

As the snout of the glacier receded northward, extensive morainal* areas were uncovered on the floor of the Trench. Meltwater draining southward away from the glacier terminus and along ice-marginal channels deposited sand and gravel along sinuous courses across this terrain (Figure 2.2). Further north, a large lake (Glacial Lake Invermere) formed during deglaciation of the area now occupied by Columbia and Windermere Lakes. The lake stood at approximately 850 m above sea level, 40 m to 50 m higher than the modern lakes. Southerly drainage was restricted by terraces of late-glacial gravels and older drift* which extended across the Trench south of Canal Flats.

The Rocky Mountain Trench and valleys in the mountains were ice free before about 11 000 years ago (Fulton, 1971; Clague, 1975). It is likely that by 10 000 years B.P., mountain glaciers were not much more extensive than those of the present day.

During postglacial time, rivers became entrenched into Fraser Glaciation deposits, and in some places bedrock canyons were eroded. Most downcutting occurred within a few thousand years of deglaciation. Former outwash* plains and lake floors now constitute terraces in both the Trench and mountain valleys. Floodplains* formed along many watercourses, both large and small. Alluvial fans* developed where steep mountain creeks emerged onto level ground. A mantle of eolian (windblown) sand and silt has accumulated over large parts of the floor of the Rocky Mountain Trench and other large valleys since deglaciation. Slopes have been modified by weathering*, mass movement and accumulation of talus*, avalanche debris, and other forms of colluvium*.

2.3 PHYSIOGRAPHIC REGIONS

For descriptive purposes, the study area has been divided into physiographic regions (after Holland, 1964). These are areas within which there is similarity of topography and relief, bedrock type and structure, geological history, and surficial materials. Physiographic regions of the East Kootenay region are shown in Figure 2.3 and their characteristics are summarized in Table 2.2. Simplified bedrock geology of the area is illustrated in Figure 2.1. Geological information in this section and in Table 2.2 is taken from Henderson (1954), Leech (1954, 1958, 1979), Price (1961, 1965), Rice (1937) and Schofield (1915).

2.3.1 PURCELL MOUNTAINS

Within the study area, the Purcell Mountains are underlain by metamorphic* and sedimentary* rocks, chiefly quartzite*, argillite*, limestone* and dolomite*. Although similar rocks form bold

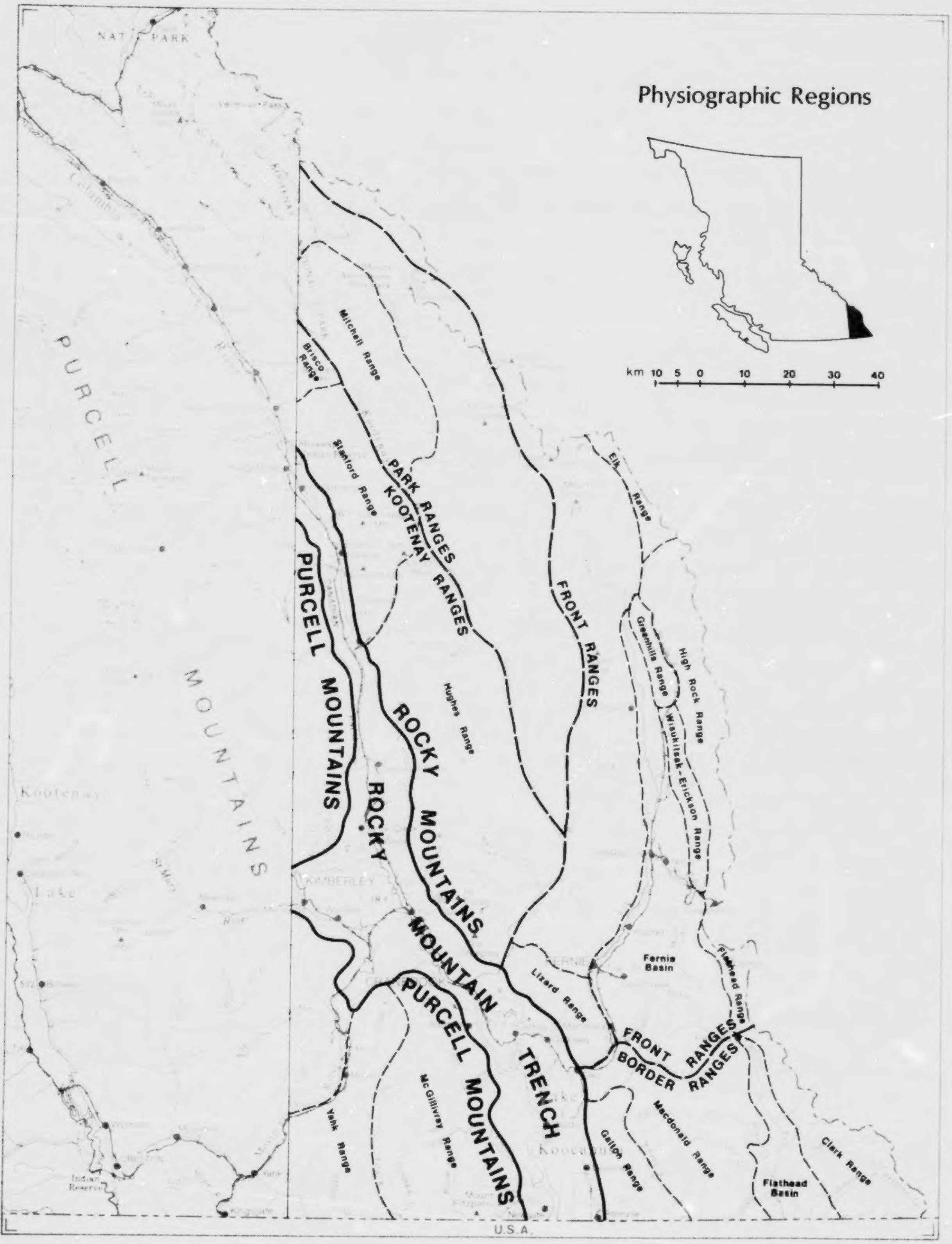

Physiographic Regions
km 10 5 0 10 20 30 40
NAT. PARK
PURCELL
MOUNTAINS
Kootenay
Lake
Brisco Range
Mitchell Range
Stanford Range
PARK RANGES
KOOTENAY RANGES
FRONT RANGES
Elk Range
High Rock Range
Greenhills Range
Wisukitsak-Erickson Range
Hughes Range
PURCELL MOUNTAINS
ROCKY
ROCKY MOUNTAINS
KIMBERLEY
ROCKY MOUNTAIN TRENCH
PURCELL MOUNTAINS
FERNIE
Fernie Basin
Lizard Range
Flathead Range
FRONT RANGES
BORDER RANGES
Macdonald Range
Galton Range
Clark Range
Flathead Basin
McGillivray Range
Yahk Range
Koocanusa
Indian Reserve
U.S.A.

Figure 2.3 Physiographic regions (after Holland, 1964).

and steep terrain along the crest of the Purcell Mountains, topography in the Yahk and McGillivray Ranges is relatively subdued (Plate 2.1). This is possibly the result of relatively less tectonic uplift of this area as compared to the high Purcells and the Rockies. It may also reflect the overriding of most of this area by ice during Fraser (and probably earlier) glaciations. Alpine glacial landforms (shallow cirques) are limited to high land in the vicinity of Mount Fitzpatrick, Yahk Mountain, and a few other isolated summits that rise above 2000 m. Summits and ridge crests are typically rounded or gently undulating, summits are low, range of relief is small, and valley sides have low gradients, particularly in the Yahk Range (Table 2.2).

Plate 2.1 View southeastward across the McGillivray Range of the Purcell Mountains from a viewpoint near Moyie Lake. Relatively gentle slopes and rounded summits are typical of this area, which was overridden by ice during Fraser Glaciation.

Most upland areas are mantled by at least a thin covering of drift. Extensive drift-covered areas occur in the Yahk Range and in the northern part of the McGillivray Range. Bedrock outcrops and colluvial slopes are restricted to steep terrain, convex breaks of slope, and some ridge crests. Bedrock and colluvium are widespread only in steep terrain around Moyie Lake and Moyie River valley (atypical for the Purcells), and in high land at the southern end of the McGillivray Range between Yahk River and upper Bloom Creek.

TABLE 2.2

CHARACTERISTICS OF PHYSIOGRAPHIC REGIONS

Physiographic Regions	Highest Peaks (m)	General Summit Elevations (m)	Local Range of Relief[1] (m)	Valleyside Slopes[2] (m/km)	Typical Landforms	Bedrock Geology
McGillivray Range	Fitzpatrick 2234 Baker 2208 Connell 2167	1675 to 2200	600 to 750 900 along E edge	250 to 350 450 along E edge	- rounded summits & relatively gentle valley side slopes; few cirques, V-valleys	- quartzite, limestone, argillite, andesite; open folds & gentle dips
Yahk Range	Olson 1973 unnamed 1980 Lodge 1858	1675 to 2000	460 to 670 800 bordering Moyie valley	150 to 245 550 bordering Moyie valley	- rounded summits & ridge crests; slopes relatively very gentle; no cirques, V-valleys	- quartzite & argillite; open folds and gentle dips
Other Purcell Ranges		2450	600 to 900	150 to 500	- rounded summits & ridges; relatively gentle slopes - major glacial meltwater channels	
Rocky Mountain Trench		1070	120	<100	- drumlins & undulating till; outwash channels & terraces; Kootenay River floodplain; lacustrine silt terraces	- chiefly Quaternary sediments; bounded by fault scarps
Clark Range	King Edward 2800 Starvation 2835 Scarpe 2632	2280 to 2750	750 to 900 1050 bordering Flathead valley	450 to 600	- sharp peaks & ridge crests; rocky cliffs & buttresses, V-valleys; structural control; rugged terrain	- argillites, sandstone, limestone; shallow folds
Flathead Valley		1375	150	<50	- undulating till; Flathead River floodplain, terraces	- Tertiary & Quaternary sediments; fault bounded
Macdonald Range	Unnamed 2665 Overfold 2470 Inverted 2380	2225 to 2380	850 to 910	450 to 600 250 to 300 in Cabin Creek basin	- moderately rugged terrain, with structural control; some prominent ridges; many small cirques; U-valleys	- chiefly argillites to west; limestone, dolomite & shale elsewhere; dips generally southwestward
Galton Range	Unnamed 2392 2290 2268	1975 to 2275	750 to 910 (east side) 1050 to 1220 (west side)	450 to 600	- steep V-valleys on west side; cirques & U-valleys on east side	- argillite, sandstone & siltstone, limestone, dolomite; faultbounded syncline
Hughes Range	Fisher 2846 Morro 2912 Gagnebin 2896	2300 to 2800	920 to 1300 1850 adjacent to Trench	150 to 600 up to 760 adjacent to Trench	- rugged terrain displaying strong structural control; sharp peaks & ridges; many cirques, U-valleys; some karst features	- chiefly limestone, dolomite, shale, argillite & quartzite; faulted & folded along north-south alignment; dips variable
Stanford Range	Indian Head 2680 Aeneas 2680 Fairmont 2625	2285 to 2685	1400 to 1800	300 to 450	- rugged terrain with sharp, steep-sided peaks & ridges; structural control; lower valley sides relatively gentle; cirques & V-valleys	- chiefly dolomite & limestone, minor shale & gypsum, complex structure with longitudinal & transverse faults

TABLE 2.2: (CONT'D)

Physiographic Regions	Highest Peaks (m)		General Summit Elevations (m)	Local Range of Relief[1] (m)	Valleyside Slopes[2] (m/km)	Typical Landforms	Bedrock Geology
Mitchell Range	Tangle Harkin Unnamed	2788 2960 2889	2450 to 2900	1220 to 1520	400 to 600	- sharp peaks & ridge crests; some structural control; cirques & V-valleys; rugged terrain	- limestone, dolomite, minor shale; quartzite & phyllite; horizontal or gentle dips (except steeper in Mitchell Range)
Assiniboine massif	Assiniboine	3600	2900 to 3600	1850	extremely variable	- spectacular alpine glacial landforms; some structural control; cirque glaciers & moraines	
other Park Ranges	King George Harrison Russell	3420 3360 3050	2440 to 3360	1075 to 1500	300 to 600		
Lizard Range	Unnamed	2320	2000 to 2300	900 1100 along flanks of range	460 to 760	- prominent ridges with sharp crests & many cliffs; karst; some cirques; strong structural control	- limestone, dolomite, minor shale except in northeast where argillite & quartzite occur
Fernie Basin	Flathead Ridge Limestone Ridge Corrigan	2200 2450 2366	1980 to 2200	450 to 700	245 to 450	- rounded or undulating ridge crests above steeper valleysides; major scarp flanking Elk Valley	- sandstone, shale, conglomerate & coal; folded & faulted; complex basin structure
Flathead Range	Ptolemy Darrah	2815 2750	2280 to 2600	920	mountains >600 lower valleys 150 to 250	- mountains rise steeply above gentle lower slopes, well-developed cirques; sharp peaks & ridges	- chiefly limestone & dolomite, dipping steeply south-westwards, & westward dipping thrust faults
High Rock Range	Tornado Courcelette Baril	3100 3045 3000	2300 to 2800 (elevations increase northwards)	850 to 1200 (relief increases northwards)	mountains >2000 lower valleys 700 to 1000	- similar to Flathead Ridge; some structural control	- limestone & dolomite dipping southwestwards & westward dipping thrust faults
Elk Range	Loomis Oblum	2810 2690	2600 to 2750	1050 to 1100	460 to 600	- cirques on steep, fretted ridge; strong structural control	- limestone, quartzite; steep dip to west
Erickson Ridge Wisukitsak Range Greenhills Range	Erickson Lyne unnamed	2486 2703 2408	2000 to 2300	900 to 1200	360 to 600	- steep-sided ridges & subdued mountains	- limestone, dolomite, sandstone & quartzite, dipping westwards
other Front Ranges	Bisaro Peck Abruzzi Sir Douglas	2840 2922 3101 3360	2280 to 3360 (elevations increase northward)	900 to 1500	300 to 600	- rugged mountainous terrain; many cirques & U-valleys; strong structural control	- limestone, dolomite, sandstone, shale, siltstone; thrust faulted & folded

[1] Elevation difference between summits and adjacent valleys measured over distances of 5 to 10 km.
[2] Mean valleyside gradients; steep upper slopes not included.

There are narrow belts of flat land along most valley floors. Creeks of moderate size such as Bloom, Teepee, and Gold River flow on narrow, poorly drained floodplains that here and there are constricted by alluvial fans debouching from minor tributaries. Along the eastern margin of the Purcell Mountains adjacent to the Rocky Mountain Trench, some of the larger watercourses such as Gold, Skookumchuck, Dutch, and Findlay Creeks are deeply incised. They occupy steep-sided rocky gorges which are flanked by drift terraces.

The lower eastern slopes of the Purcell Mountains are traversed by many glacial meltwater channels and adjacent spreads of fluvioglacial* gravels are common. These channels run roughly parallel to the western margin of the Trench. They are steep-sided, flat-floored, sinuous ravines which range in depth from a few metres to over 300 m. Examples include the valleys of Mather and Lost Dog Creeks west of Ta Ta Creek, and the ravine containing Kiakho Lakes west of Cranbrook. Some channels have no through flowing drainage at the present time. Others contain small meandering creeks, lakes, and pockets of organic terrain. A few meltwater channels remained permanently occupied by rivers that were diverted from their preglacial courses, such as Moyie River (for 10 km upstream from the north end of Moyie Lake), Skookumchuck Creek (southward flowing reach) and lower Gold Creek.

2.3.2 ROCKY MOUNTAIN TRENCH

The Rocky Mountain Trench is a major topographic feature which borders the western front of the Rocky Mountains from 47° N in northwestern Montana, through British Columbia to beyond 59° N, a distance of over 1500 km. It follows a major zone of crustal weakness that is possibly an ancient continental margin.

In the study area the Trench follows a tectonic depression that was caused by blockfaulting* during the Tertiary Period* (Figure 2.4), (Leech, 1966; Clague, 1974). The steep, western front of the Rockies is a major fault scarp* which rises about 1500 m above the Trench floor. Quaternary sediments and weakly consolidated late Tertiary sediments beneath the Trench floor are over 1000 m thick in places. Bedrock that underlies these materials is part of the downfaulted* and tilted western fault block. Its surface is irregular. Rock outcrops on the Trench floor are the exposed parts of ridges that separate deep structural basins. In general, the bedrock surface rises gradually westwards into the hilly terrain of the eastern Purcell Mountains. The marked asymmetry of the Trench thus reflects structural control.

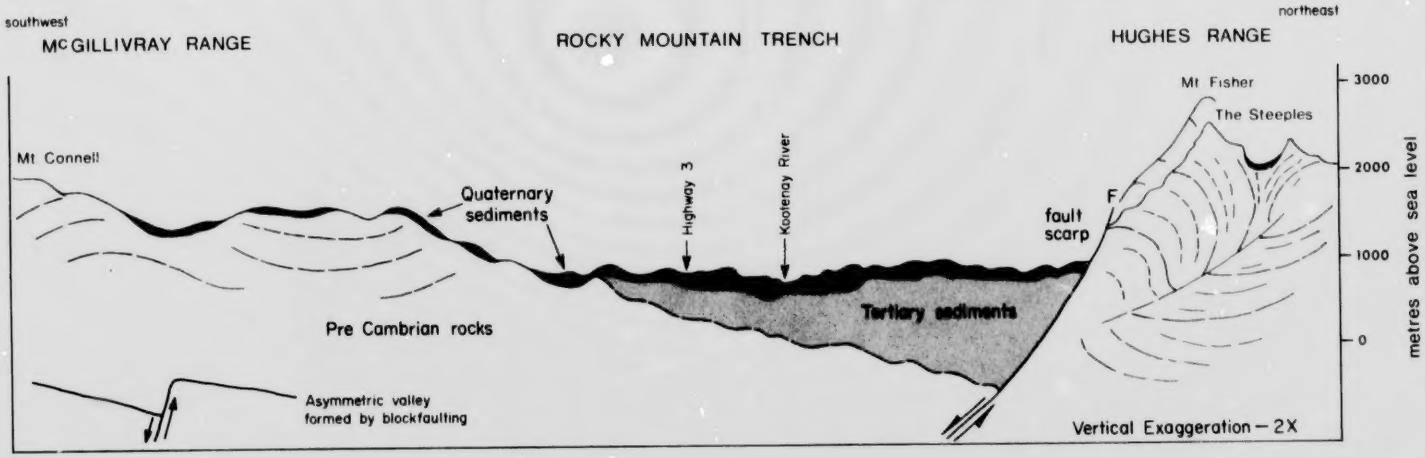

southwest
McGILLIVRAY RANGE
ROCKY MOUNTAIN TRENCH
northeast
HUGHES RANGE
Mt Connell
Quaternary sediments
Highway 3
Kootenay River
fault scarp
F
Mt Fisher
The Steeples
3000
2000
1000
0
metres above sea level
Tertiary sediments
Pre Cambrian rocks
Asymmetric valley formed by blockfaulting
Vertical Exaggeration – 2X

Figure 2.4 Schematic cross-section of Rocky Mountain Trench near Cranbrook. Illustrates structural control of asymmetry, and distribution of Tertiary and Quaternary sediments.

The floor of the Trench is 3 to 16 km wide and varies between 760 and 1060 m in elevation. It consists of undulating drift terrain with occasional bedrock hills. The Kootenay River and its major tributaries occupy shallow, flat-floored valleys (Plate 2.2).

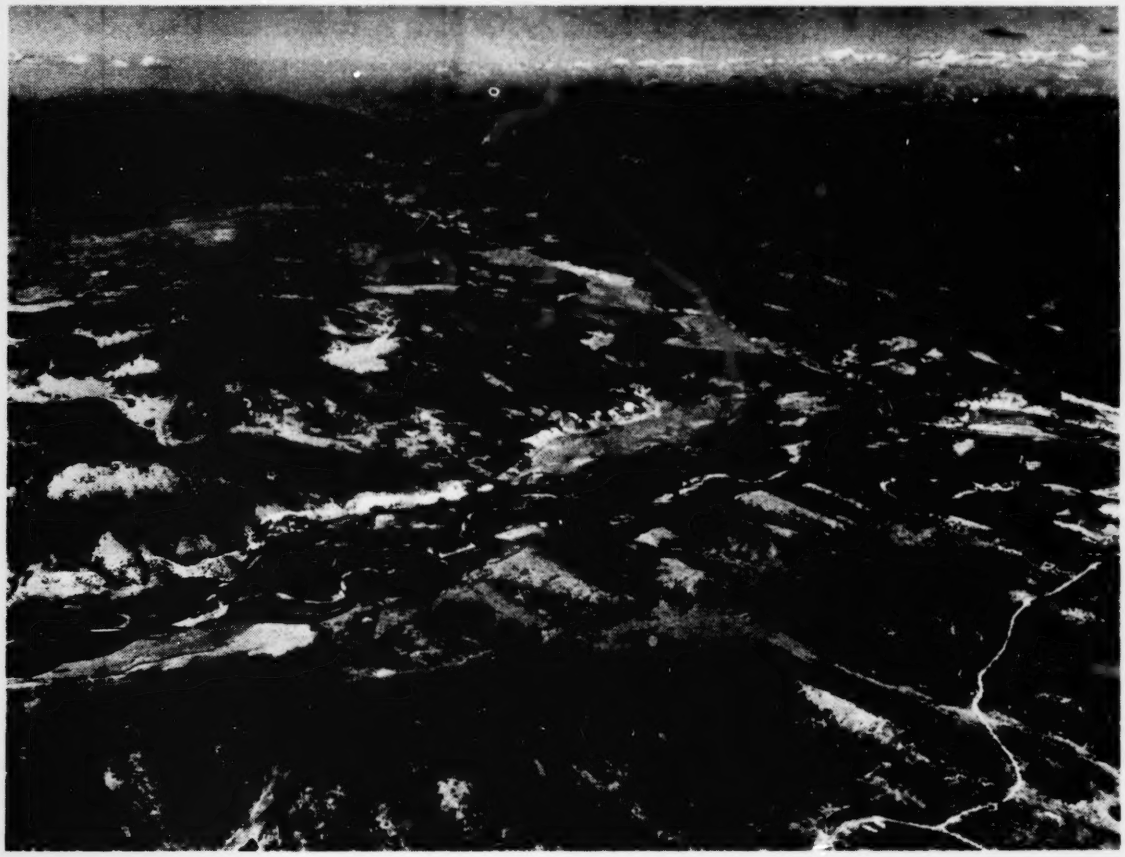


Plate 2.2 View northward along the Rocky Mountain Trench from a viewpoint near Cranbrook. St. Mary River flows eastward to join meandering Kootenay River at Fort Steele. The Trench floor consists of broad floodplains along the two rivers, and streamlined morainal topography. Till overlying older fluvial gravels and lacustrine silts is exposed in scarps that bound the floodplain of St. Mary River. Canada Department of Energy, Mines and Resources, T31L-133.

For descriptive purposes, the Trench can be subdivided into three units:

1. South of Ta Ta Creek (49°45'N), the lowland is relatively broad. It consists chiefly of rolling terrain on drumlinized* till with local relief of 15 to 40 m. The till areas occur as 'islands' bounded by sinuous, shallow outwash channels, as for example in the Tobacco Plains Indian Reserve area. Most of these channels do not contain permanent drainage. In fact, they tend to be relatively arid due to the low water retention capacity of underlying sands and gravels. The Kootenay and St. Mary Rivers are incised below the general level of the Trench floor (Plate 2.2). The Kootenay River flows through alternate braided* and meandering* reaches on a floodplain that is 1 to 3 km wide. Scroll patterns* and other old meander scars on the floodplain indicate that channels commonly shift and bank erosion is active. The floodplains of both rivers and the basin of Lake Koocanusa are bounded by scarps, 5 to 30 m high, and terraces.

2. Between Ta Ta Creek and Canal Flats (49°45'N to 50°10'N) the floor of the Trench is narrower. Landforms and surficial materials are generally similar to those of the southern section, but also include large tracts of irregularly undulating and terraced terrain on fluvioglacial gravels.

3. North of Canal Flats the Trench landscape is dominated by Columbia and Windermere Lakes and low-lying wetlands of the Columbia River floodplain. The lakes are flanked by frayed scarps and gently undulating benches of lacustrine* silt, alluvial fans, and areas of undulating till which are traversed by deeply incised meltwater channels.

2.3.3 ROCKY MOUNTAINS

Within southern British Columbia and Alberta, the Rockies consist predominantly of sedimentary rocks. Deformation and uplift of these sediments took place during Cretaceous* and early Tertiary time (Laramide Orogeny*). The mass of sediments was thrust eastward over younger strata lying along the western margin of the Great Plains. Shearing and contortion during deformation gave rise to the north-northwest to south-southeast trending faults and folds that control the present day linear topography (Plate 2.3).

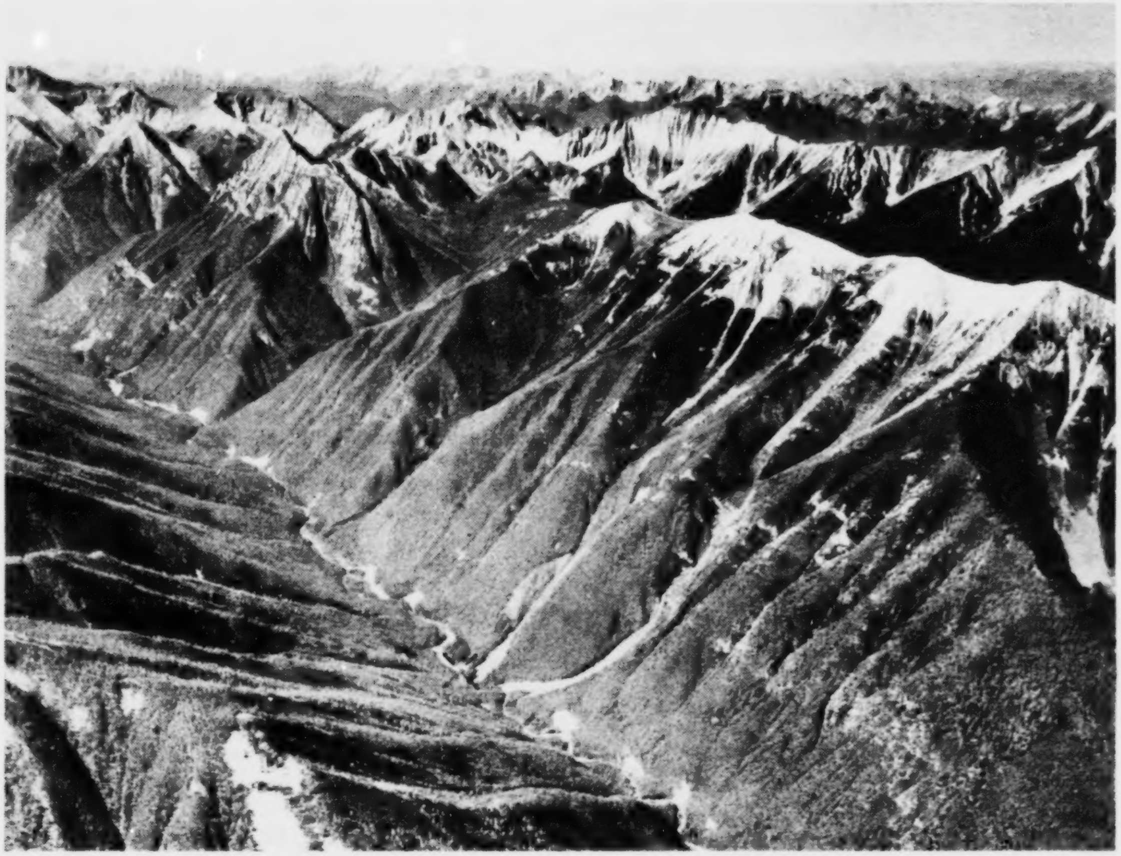


Plate 2.3 View up Blackfoot Creek near Whiteswan Lake in the Park Ranges of the Rocky Mountains illustrates typical features of this physiographic region. Province of British Columbia, BC 891:61.

The character of terrain within the Rocky Mountains is variable, due to differences in structural style and rock types. Accordingly, the region is subdivided into several smaller units. These are indicated on Figure 2.3 and typical features are listed in Table 2.2. Descriptions are restricted to those parts of physiographic regions that lie within the study area.

KOOTENAY RANGES

This physiographic unit includes the Stanford and Hughes Ranges and the southern tip of the Brisco Range. These ranges are bounded to the west by the eastern fault scarp* of the Rocky

Mountain Trench and to the east by the structurally controlled broad valleys of Kootenay, White, and Bull Rivers.

The Stanford Range is structurally complex. It consists of faulted and folded carbonate rocks* and shales*. Several major faults parallel the northwest to southeast trend of the range. In addition, many transverse thrust faults cross the southwestern part of the range between Kootenay River and Tatley Creek (Henderson, 1954). In general, faults and shale outcrops tend to be followed by valleys and depressions whilst the fault blocks constitute ridges and high peaks. Valleys such as that of Windermere Creek show abrupt changes in direction as a result of structural control.

The geology of the northern and eastern parts of the Hughes Range is the same as that of the Stanford Range, chiefly limestone, dolomite*, and shale. Rock types of the southwestern part of the range are similar to those of the southwestern Purcell Mountains, chiefly argillite and quartzite. Structures in the Hughes Range are north to south trending folds and faults, and larger valleys, such as Lussier, Coyote, Galbraith and Quinn, run parallel to these lineaments. Top of the World area lies within a broad, open syncline* in dolomites and limestones.

Topography in the Stanford and Hughes Ranges is rugged and complex. Deeply incised valleys of tributaries of Kootenay, White, and Bull Rivers divide the main ranges into a number of smaller units such as the Van Nostrand Range which is bounded by Quinn and Coyote-Galbraith valleys. Local relief is greatest along the western edge of the ranges where tall peaks such as Fairmont Mountain, Mount Fisher and the Steeples stand adjacent to the Trench floor.

Peaks which rise above 2400 m were not overridden by ice during Fraser Glaciation. Consequently, they display sharp summits with almost vertical faces, and knife-edged ridges. Cirques and arêtes* are present in the higher part of the Stanford Range near Indian Head Mountain, and in the central southern part of the Hughes Range between Top of the World and Mount Fisher. Lower summits and ridge crests were overridden by ice, and tend to be rounded.

In these ranges, as in other parts of the Rockies, a strong structural control is evident in the shape of individual peaks and in the detailed morphology of the valleys (Plates 2.4 and 2.5). This is significant since it determines the location of cliff bands, other steep rocky slopes, and related colluvial slopes. In the western part of the Stanford Range, precipitous rocky slopes occur

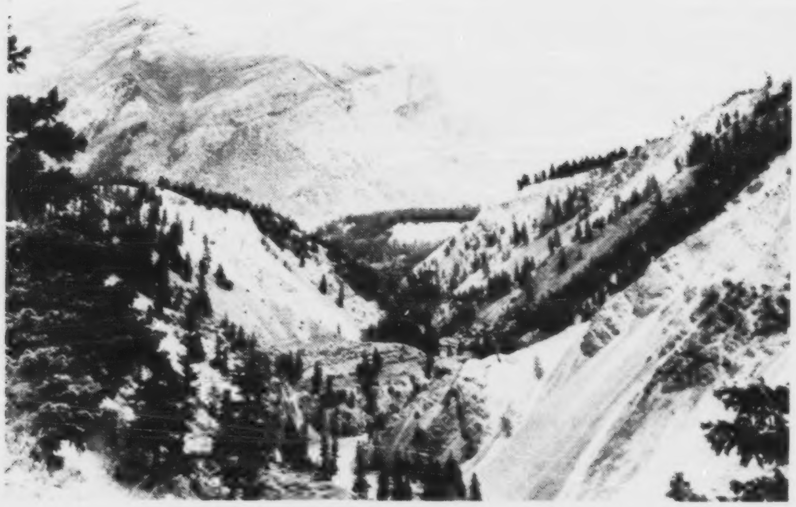


Plate 2.4 View northeastward up lower Wigwam River to Mt. Broadwood. Dipping strata are part of Broadwood anticline. The most prominent cliff-band, China Wall, is composed of massive limestone of the Palliser Formation.

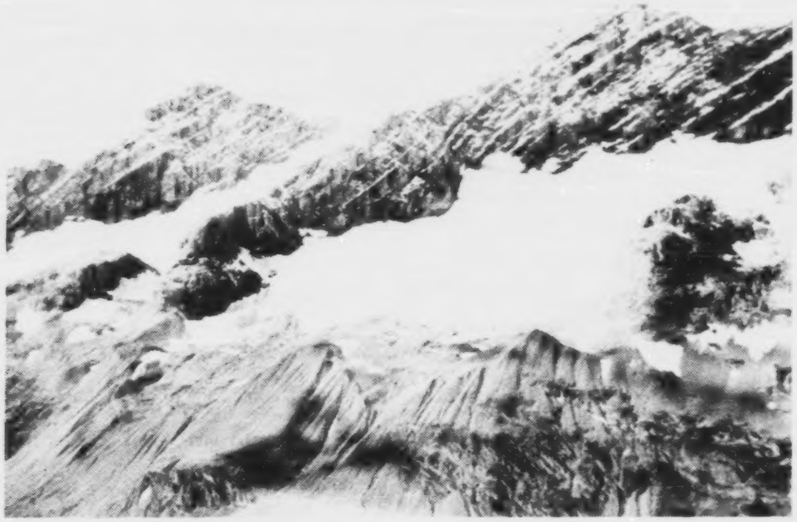


Plate 2.5 Cirques near Mt. Abruzzi in the Front Ranges of the Rocky Mountains: asymmetry of ridges is controlled by dipping strata. Gullied moraine ridges indicate extent of recent expansion of cirque glacier.

in longitudinal valleys* that are possibly fault controlled. Valleyside gradients vary in response to rock resistance to erosion and proximity to steep-gradient creeks, such as those draining the western slopes.

In general, there are rock outcrops on summits, ridge crests and relatively steep slopes; valleysides below rock exposures and slopes susceptible to avalanches are mantled by colluvium. Colluvium covered slopes are predominant along the steep mountainsides overlooking the Trench between the Steeples and Teepee Mountain. Till covers gently sloping ground and areas at relatively low elevations. Most valleys of moderate size, such as those of upper Lussier and Wild Horse Rivers and Windermere Creek, contain stretches of narrow, gravelly floodplain alternating with rocky gorges. The latter tend to be located where valleys are aligned transverse to the "grain" of the terrain. Lussier River cuts across the Hughes Range in a spectacular gorge west of Alces Lake. Between Gibralter Rock and Canal Flats, Kootenay River cuts across the ranges in a valley that is steep-sided, but floored by terraces, floodplain, and irregular drift.

There are numerous collapse-sinkholes* in the valleys of Lussier River and Coyote Creek. They formed due to solution of gypsum* beds which locally underlie till. The sinkholes are typically steep-sided, circular depressions of less than 90 m diameter and less than 15 m deep. Many contain standing water. Till is exposed in the sides of the depressions. Lack of vegetation, unstable side slopes, and the presence of fallen trees suggest that several sinkholes may have formed recently, or that enlargement may still be occurring. In 1967 a sinkhole opened up overnight on the floor of a gypsum mine (Western Gypsum Mines Ltd.) east of Invermere. The till-mantled gypsum karst* of Lussier and Coyote valleys has been described by Wigley et al., (1973).

The valleys of Kootenay River north of Gibralter Rock and White River north of White Swan Lake lie along a belt of easily eroded phyllites*. They contain broad (2-8 km wide) tracts of gently sloping and undulating terrain with till along lower valleysides and river terraces, alluvial fans, and floodplains along the centre of the valleys. Rivers are incised 50 to 100 m below the general level of the valley floor. In places they occupy gorges in drift or bedrock.

PARK RANGES

The Park Ranges extend northward from the confluence of Bull River with Quinn Creek (Figure 2.3). Summit elevations rise gradually northward from about 2800 m near Quinn Creek to 3600 m at

Mount Assiniboine. Further north the Park Ranges contain many of the highest and best known mountains of the Canadian Rockies, such as Mount Robson.

These ranges consist of horizontal or gently dipping sedimentary and metamorphic rocks sliced by north-northwest to south-southeast trending, westward-dipping thrust faults*. This arrangement has given rise to a series of parallel ridges and valleys (Plate 2.3). Dips* are somewhat steeper in the Mitchell Range and adjacent to faults. Relatively resistant limestones and quartzites have been fretted and sculpted by weathering and glacial erosion to form soaring peaks bounded by castellated walls and buttresses (Plate 2.6). Individual mountains are shaped according to their structure, and cirques, arêtes and glacial troughs tend to be asymmetric. Small cirque glaciers*, recent moraines, and rock glaciers* are common at high elevations in the northern part of the ranges, especially in Assiniboine Provincial Park.

Plate 2.6 View towards Mt. Assiniboine from Citadel Pass: Front Ranges of the Rocky Mountains.

Longitudinal valleys, such as that of North White River, follow belts of phyllite or shale, or fault lines, and are typically broad and open. Many are wide glacial troughs with relatively gentle drift-covered slopes close to river level, and narrow floodplains criss-crossed by braided channels indicating relatively high debris loads. The gentle slopes grade upward into steeper valley sides and avalanche slopes which are mantled by colluvium. These in turn give way to rock bands and rocky ridge crests. Transverse valleys* vary in width. They are broad with floodplains in phyllites and shales, and narrow with gorges in limestones and quartzites.

Features resulting from limestone solution are widespread in the Park Ranges. Small collapse sinkholes occur here and there, most obviously in alpine areas where drift is thin and vegetation is sparse. Cave entrances can be seen on many rock faces. Valley of the Rocks in Mount Assiniboine Provincial Park is a chaotic mass of tumbled limestone blocks. Box canyons are common in limestone terrain, and although not specifically karst features, they result from a combination of solution and river abrasion. Canyons two or three metres wide, and several times deeper, occur on Palliser and Cross Rivers.

FRONT RANGES

The Front Ranges occupy the east-central portion of the study area and extend eastward and northward into Alberta. They contain several subsidiary ranges and the Fernie Basin (Figure 2.3). In general, this region consists of a series of structurally controlled ridges and valleys which trend roughly north-south.

The Fernie Basin is a complex syncline within which Mesozoic* sandstones, shales, conglomerates and coal overlie older limestones (Figure 2.5). The valley followed by Highway 3 between Morrissey and Crowsnest Pass (Elk River - Michel Creek) follows the strike of Fernie Basin rocks and has been excavated in relatively erodible shales of the Fernie Group, (Price, 1962).

The rocks of the Fernie Basin, particularly the shales and thinly bedded sandstones, are relatively susceptible to erosion and consequently this area consists of comparatively subdued topography (Plate 2.7). The highest land, for example Flathead, Morrissey and Fernie Ridges and Fording Mountain, is underlain by relatively resistant sandstones and conglomerates. Within the uplands of the Fernie Basin, valleys are shallow with gently sloping sides. Steep slopes and greatest local relief are found along the flanks of Elk River valley, for example along the western sides of Fernie and Morrissey Ridges.

The gently sloping upland areas of the Fernie Basin and hillsides at low elevations along Elk River valley are mantled by till. Steeper slopes are colluvium covered. The characteristics of

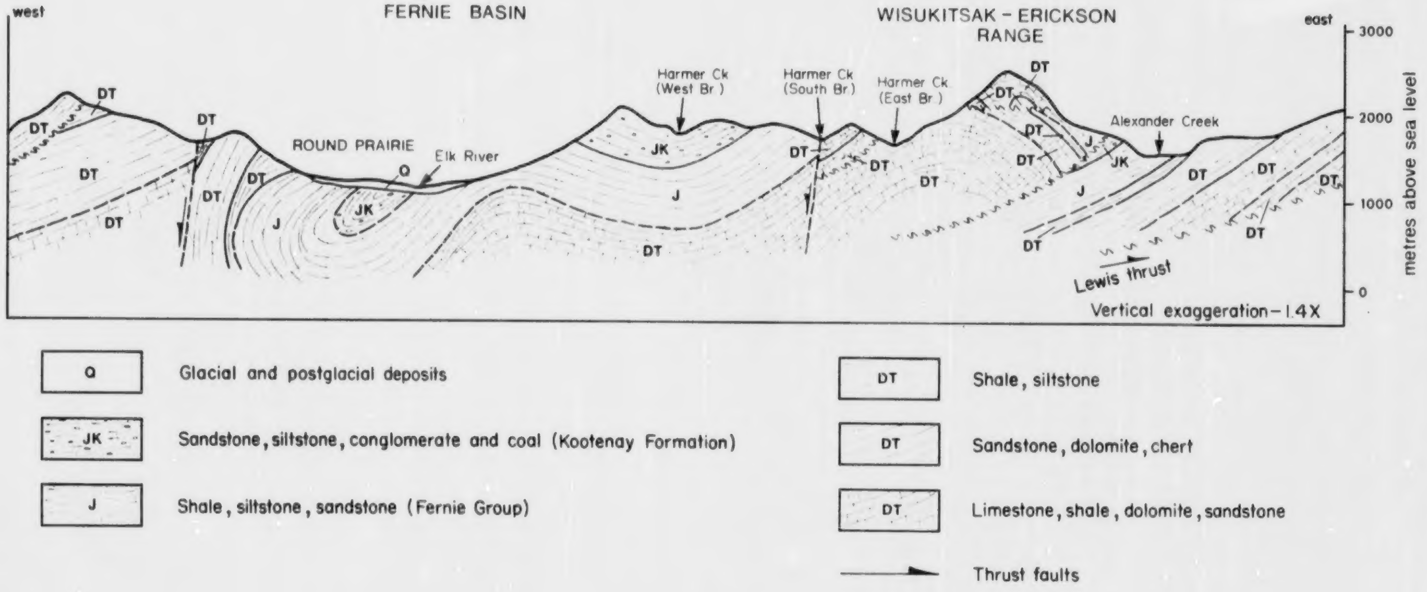

west
FERNIE BASIN
WISUKITSAK - ERICKSON RANGE
east
3000
2000
1000
0
metres above sea level
Harmer Ck (West Br.)
Harmer Ck (South Br.)
Harmer Ck (East Br.)
Alexander Creek
ROUND PRAIRIE
Elk River
Q
JK
J
DT
Lewis thrust
Vertical exaggeration - 1.4X
Q Glacial and postglacial deposits
JK Sandstone, siltstone, conglomerate and coal (Kootenay Formation)
J Shale, siltstone, sandstone (Fernie Group)
DT Shale, siltstone
DT Sandstone, dolomite, chert
DT Limestone, shale, dolomite, sandstone
Thrust faults

Figure 2.5 Cross-section of Fernie Basin near Elkford showing relationship between geological structure, rock types and topography (after Price, 1962).

till and colluvium are variable and are governed, to a large extent, by the type of rocks from which they were derived (sections 4.4 and 7.2). Rock outcrops are small and scattered, except on Flathead and Morrissey Ridges.

Plate 2.7 View eastwards from Morrissey Ridge across the central part of Fernie Basin and headwaters of Flathead River to Flathead Range. Subdued topography on sandstones and shales in the middle ground contrasts sharply with upstanding and steeply dipping limestones and dolomites along the skyline.

Elk River follows an irregularly meandering course with many side channels. It occupies a broad floodplain that is about one kilometre wide but constricted in places by alluvial fans. The floodplain is bounded by low river terraces, and by scarps and benches of lacustrine silt and clay. Extensive areas of fine textured lacustrine deposits are present between Sparwood and the mouth of Fording River.

The ridges that surround the Fernie Basin consist of upthrust or steeply dipping resistant rocks (Figure 2.5). Thrust faults and strata dip westward or southwestward, so that the steepest (scarp) slopes face eastward. Valleys lie along fault lines or belts of less resistant rocks, such as shales, siltstones, and thinly-bedded sandstones. The Flathead Range, High Rock Range and Elk Range consist of massive limestones and dolomites that have been carved by alpine glaciation to form a line of prominent scalloped peaks and cuspate ridges along the British Columbia-Alberta boundary

(Plate 2.7). Very steeply dipping and vertical strata in the Elk Range and ranges adjacent to the west have produced spectacular crenulated buttresses, flat-iron* formations, and jagged skylines. Greenhills Ridge, Wisukitsak Ridge, and Erickson Ridge are structurally similar to ranges along the provincial boundary, but include some sandstones and quartzites in addition to limestone. They constitute comparatively low topography with rounded crests and no alpine glacial forms.

The Lizard Range consists of a variety of rock types in complex structural relationships. Argillites and quartzites constitute relatively subdued topography north and west of Sand Creek. The precipitous backbone of the Lizard Range consists of an overturned and steeply dipping sequence of limestone, dolomite and minor shale. Glacial erosion combined with structural control has resulted in extremely rough terrain with prominant parallel ridges. Karst features are widespread, particularly collapse-sinkholes and limestone pavement. The southwestern part of the range is made up of folded limestones (Broadwood anticline) which continue southeastward across the transverse Elk River valley to Mount Broadwood (Plate 2.4).

Bedrock geology of the remaining Front Ranges which lie west of Elk River valley has not been mapped in detail. However, mountain ridges are typically thrust sheets of southwesterly dipping or folded strata. Upstanding rock types are limestone, dolomite and some sandstone, whilst shales and siltstones outcrop at low elevations. Alpine glacial forms are present at high elevations but they are typically asymmetric due to strong structural control (Plate 2.5). Most major valleys are glacial troughs. Elevations increase northward. Cirque glaciers, moraines and tarns* are common in the higher ranges.

Surficial materials are typically distributed, with till mantling low gradient slopes, especially at low elevations, and avalanche debris and other colluvium dominating slopes of intermediate gradient and elevation. Rock outcrops on summits and ridge crests and along valleyside escarpments. Narrow gravel floodplains, river terraces and alluvial fans occur in larger valleys.

BORDER RANGES

This physiographic unit includes three northwest to southeast trending ranges and the Flathead Basin (Figures 2.3 and 2.6).

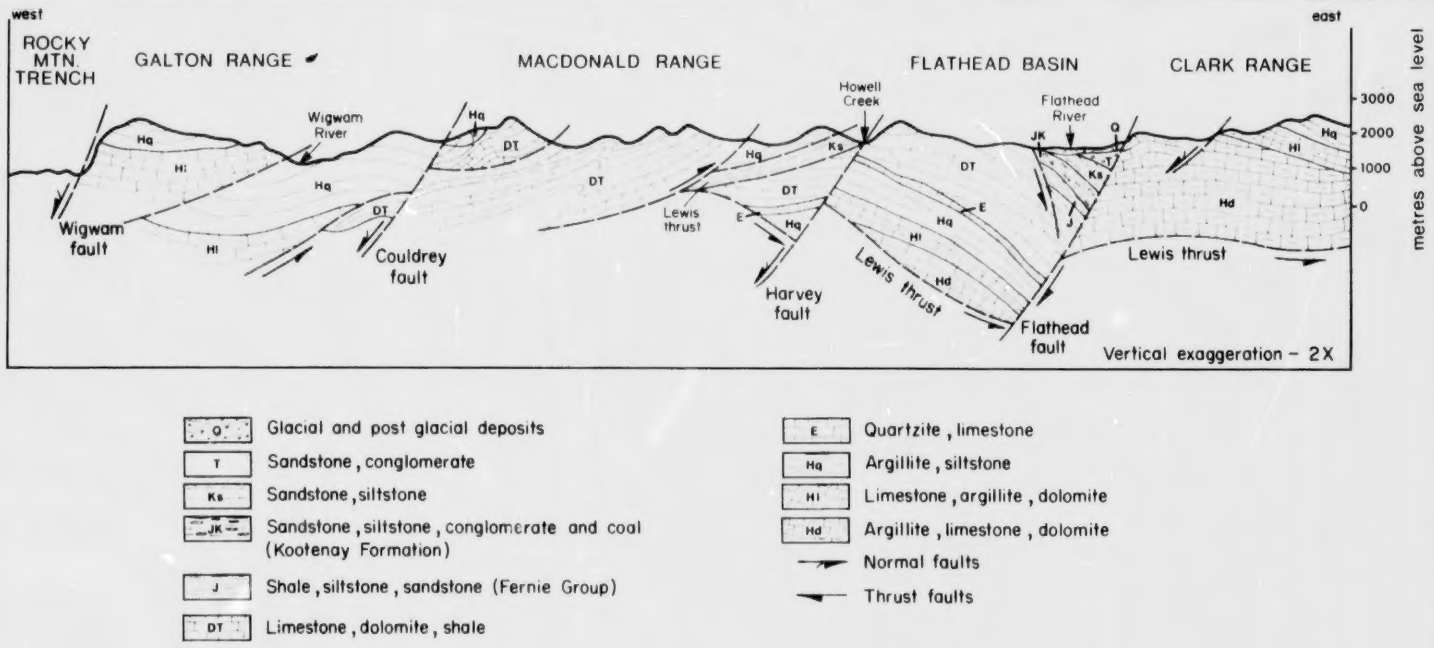

west
east
ROCKY MTN. TRENCH
GALTON RANGE
MACDONALD RANGE
FLATHEAD BASIN
CLARK RANGE
Wigwam River
Howell Creek
Flathead River
Wigwam fault
Couldrey fault
Lewis thrust
Harvey fault
Lewis thrust
Flathead fault
Lewis thrust
Hq
Hl
Hd
DT
Ks
JK
J
T
Q
E
3000
2000
1000
0
metres above sea level
Vertical exaggeration - 2X
Q Glacial and post glacial deposits
T Sandstone, conglomerate
Ks Sandstone, siltstone
JK Sandstone, siltstone, conglomerate and coal (Kootenay Formation)
J Shale, siltstone, sandstone (Fernie Group)
DT Limestone, dolomite, shale
E Quartzite, limestone
Hq Argillite, siltstone
Hl Limestone, argillite, dolomite
Hd Argillite, limestone, dolomite
Normal faults
Thrust faults

Figure 2.6 Geological cross-section through the Border Ranges (after Price, 1962).

A prominent fault-scarp* that marks the western border of the Galton Range rises abruptly from the Rocky Mountain Trench. The eastern side of the range is bounded by a major thrust-fault along the valley of Wigwam River. This fault dips gently southwestward, and is the shear plane along which the mass of the Galton Range was thrust northeastward to its present position. The mountains are composed of argillites and sedimentary rocks in a shallow syncline. Slopes are steepest and maximum local relief occurs along the western fault scarp. Creek gradients steepen downslope, and many creeks descend to the Trench floor over waterfalls and rapids. Shallow cirques occur above 2100 m along east- and north-facing slopes. Mountainsides consist chiefly of colluvium with till. Rock outcrops occur on steeper slopes and ridge crests. Rubbly morainal material is present within cirques and adjacent high valleys.

Wigwam River follows the eastern thrust fault between the southern edge of the study area and 49° 12' N (three kilometres north of Brigham Creek). The valley floor here is 1 to 1.5 km broad and occupied by a floodplain, terraces and fans which in places overlie silty lacustrine deposits. Further north, where the river trends away from the fault-line, the valley is narrower and steep sided.

The Macdonald Range consists of strata that dip generally southwestward and are gently folded and cut into thrust-sheets* by faults which also dip gently southwestward. Major normal faults* which postdate the thrust-faults also trend from northwest to southeast across the region. One of these, the Couldrey Fault, divides the Macdonald Range into two geologically distinct units. A belt of terrain eight to ten kilometres wide along the eastern side of Wigwam River is similar to adjacent Galton Range with regard to rock types, topography and surficial materials. The remainder of the Macdonald Range is geologically similar to the Front Ranges, with variations of topography due to structure and resistance of rock types to weathering and erosion. Limestones tend to form upstanding topography such as Inverted Ridge, and prominant cliff bands, such as "China Wall" on the eastern side of Mount Broadwood (Plate 2.4). Shales and siltstones underlie gentler slopes, such as those of Cabin Creek basin. Cirques occur on north- and east-facing ridges which rise above 2100 m. Surficial materials are typically distributed.

The Flathead Basin is a downfaulted area, bounded by normal faults which cut across older thrust faults and folds. The basin is underlain by a considerable thickness of Tertiary sediments, as well as Quaternary materials. In many respects it is geologically similar to the southern Rocky

Mountain Trench. Within the basin, local relief is small and slopes are gentle. Extensive areas of gently undulating terrain are underlain by thick till and fluvioglacial gravels. Many small meltwater channels cross the area and commonly contain small lakes and pockets of organic material. Flathead River and numerous small side-channels meander irregularly across a broad gravel floodplain. Narrower floodplains extend along the lower parts of tributary creeks.

The Clark Range rises steeply to the east of Flathead valley along the prominant scarp of the Flathead fault. It is underlain by gently downwarped* argillite, sandstone, siltstone, limestone and other sedimentary strata. Argillite and limestone are particularly resistant to erosion and stand as bold, massive mountains with steep, rocky buttresses. Interlayered green and red argillites give rise to particularly spectacular mountain walls along Kishinena Ridge. Alpine glacial forms occur throughout the range, and most major valleys are typical glacial troughs. Till mantles lower valley sides, although much of it has probably been removed or buried by avalanche activity. Avalanche tracks are very obvious features on most mountainsides.

Chapter Three

Chapter Three

TERRAIN MAPPING

3.1 INTRODUCTION

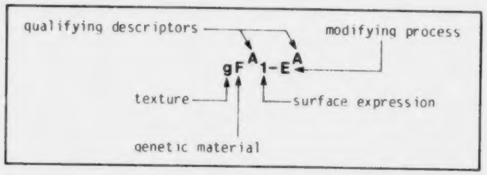
The terrain classification system and mapping methods that were used for terrain maps of the East Kootenay region are described in this chapter. This information is intended to give the reader a better understanding of the data portrayed on terrain maps with respect to both their substantive content and their reliability.

In general, the purpose of terrain mapping is to record those properties of surficial materials and landforms that are relevant to the assessment of land use potential and resource values. It also provides a basis for the mapping of soils, vegetation, and other biophysical characteristics of the landscape. Possible land uses and resources are many and varied. They range from essentially non-consumptive activities such as hiking and skiing, through "renewable resource" industries such as agriculture and forestry, to long-term and irreversible processes such as urban development and mineral extraction. Consequently, it is desirable to obtain data related to numerous different characteristics and properties of the terrain, far more in fact, than can actually be shown on a map. Thus the choice of characteristics to be recorded is a major issue. Those selected for the terrain mapping system that is presently in use in British Columbia were chosen so as to provide the basis for interpretations for as great a range of land use as possible, especially when applied in conjunction with soils data.

Terrain maps show a mosaic of small, irregularly shaped areas which are referred to as "terrain units" (Figure 3.1). Each terrain unit is described by a "terrain unit symbol"(section 3.2.5) which consists of several letters that are defined individually in the legend of the 1:50 000 scale terrain maps (Appendix B). In delimiting terrain units, the mapper has attempted, ideally, to outline areas that are homogeneous with respect to landforms, surficial materials, and geological processes*. In reality however, much of the land surface is variable and complex, and many terrain units consist of a mixture of terrain types. These are referred to as "composite units" (section 3.2.5).

LEGEND

B.1 EXPLANATION OF LETTER NOTATION



B.2 GENETIC MATERIALS

LETTER SYMBOL	NAME (PROCESS STATUS[1])
A	anthropogenic (A)
C	colluvial (A)
E	eolian (A)
F	fluvial (I)
F^G	fluvioglacial (I)
I	ice (A)
L	lacustrine (I)
L^G	glaciolacustrine (I)
M	morainal (I)
O	organic
O^B	organic (bog) (A)
O^F	organic (fen) (A)
O^S	organic (swamp) (A)
R	bedrock (I)
U	undifferentiated (I)

B.3 TEXTURE

LETTER SYMBOL	NAME
b	bouldery
g	gravelly
s	sandy
t	silty
c	clayey
d	diamicton
r	rubbly
a	blocky

B.[illegible] SURFACE EXPRESSION

LETTER SYMBOL	NAME
a	apron
b	blanket
f	fan
h	hummocky
l	level
m	rolling
r	ridged
s	steep
t	terraced
u	undulating

B.5 MODIFYING PROCESSES

LETTER SYMBOL	NAME (PROCESS STATUS[1])
A	avalanched (A)
C	cryoturbated (A)
D	deflated (A)
E	channelled (I)
E^G	channelled by glacial meltwater(I)
F	failing (A)
G	frost shattered (A)
H	kettled (I)
K	karst (A)
N	nivated (A)
P	piping (A)
S	soliflucted (A)

B.6 QUALIFYING DESCRIPTORS

LETTER SYMBOL	NAME
G	glacial
B,F,S	bog, fen, swamp
A, I	active, inactive (process status descriptors)

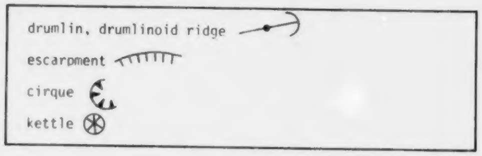
B.7 COMPOSITE UNITS

.	the components on either side of this symbol are approximately equal.
/	the component in front of the symbol is more extensive than the one that follows.
//	the component in front of the symbol is considerably more extensive than the one that follows.

e.g.

Mb//R	Mb is considerably more extensive than R.
Mb//R.Cv	Mb is considerably more extensive than R; R and Cv are of roughly equal extent.
Mb/R//Cv	R is less extensive than Mb; Cv is considerably less than R.

B.8 ON-SITE SYMBOLS



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[1] See Qualifying Descriptors for definition of Process Status.

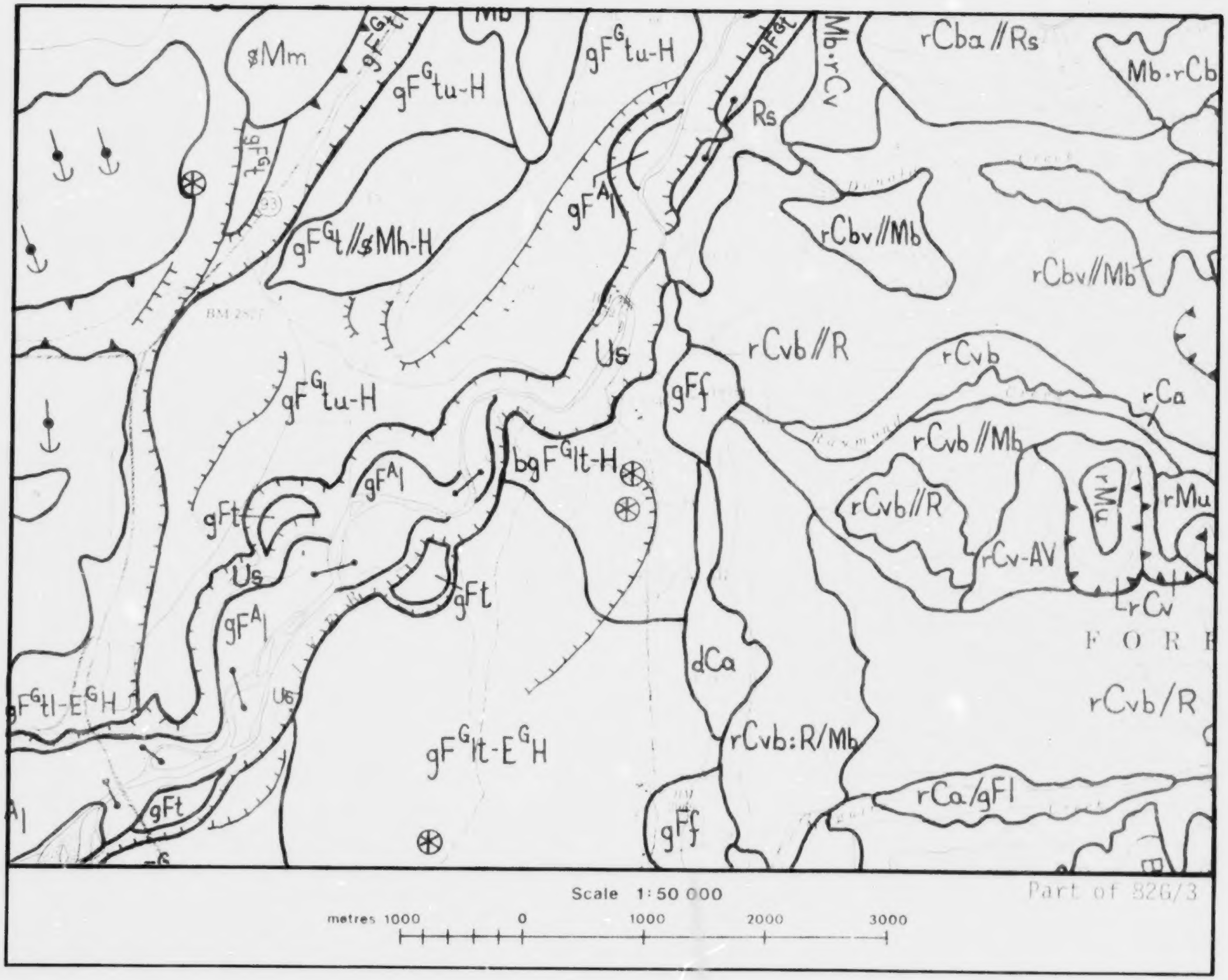
$\not{s}$Mm
gF^{G}t
gF^{G}tu-H
gF^{G}t//$\not{s}$Mh-H
gF^{A}l
Us
gF^{G}tu-H
bgF^{G}lt-H
gFt
gF^{G}tl-E^{G}H
gF^{G}lt-E^{G}H
gFf
dCa
Rs
Mb·rCv
rCba//Rs
Mb·rCb
rCbv//Mb
rCvb//R
rCvb
rCa
rCvb//Mb
rCvb//R
rCv-AV
rMu
rCv
F O R
rCvb/R
rCvb:R/Mb
rCa/gFl
Scale 1:50 000
metres 1000
0
1000
2000
3000
Part of 82G/3

Figure 3.1 Example of a terrain map and condensed legend.

Terrain maps can be prepared at various scales and at various levels of detail depending upon the objectives of a study. For example, maps at 1:20 000 are utilized for investigations of terrain suitability for settlement. Terrain maps for broad regional planning may be produced at 1:100 000 or 1:250 000. The East Kootenay terrain maps have been prepared at 1:50 000 because this scale provides information suitable both for regional planning and for preliminary overviews of small areas, such as locations for industrial activity. In the latter case, more detailed mapping, site specific investigations such as drilling, and laboratory analyses would ultimately be necessary before site plans were finalized. Terrain maps are used in conjunction with soils maps for many of the above mentioned purposes, since the latter provide information about soil moisture conditions, organic materials, and quality of topsoil, (see East Kootenay soils bulletin). A generalized terrain map at 1:250 000 scale is included in the back pocket of this report in order to provide a regional overview and to illustrate the general distribution of surficial materials.

3.2 TERRAIN CLASSIFICATION SCHEME

Terrain mapping was carried out generally in accordance with the Terrain Classification System (E.L.U.C. Secretariat, 1976). This system was initiated during the early 1970s by R.J. Fulton of the Geological Survey of Canada. It was designed as a method of rapid reconnaissance mapping from aerial photograph interpretation with limited ground checking (Fulton, et al., 1975). During 1975-76, staff of the Resource Analysis Unit[1] of the Environment and Land Use Committee Secretariat (E.L.U.C.S.) adapted Fulton's mapping scheme to the particular requirements of the E.L.U.C.S. system of biophysical mapping.

Under this system of terrain mapping, the land surface is subdivided according to the origin of the surface materials ("genetic materials"). Further divisions are then made on the basis of material texture, landforms ("surface expression"), and the effects of modern geological processes on the land surface ("modifying processes"). In addition, "on-site symbols" are used to indicate special features. All the terms and symbols used in the terrain classification system for the East Kootenay region are defined in Appendix B.

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[1] Now the Terrestrial Studies Branch of the British Columbia Ministry of Environment.

3.2.1 GENETIC CLASSIFICATION OF MATERIALS - "GENETIC MATERIALS"

It is useful to classify surficial materials according to their mode of formation or deposition since this can be identified fairly readily by aerial photograph interpretation. Also it describes, in an integrated manner, the final product of a complex sequence of processes. In other words, a certain set of properties can be ascribed to material of a particular origin, so that "genesis" is the only characteristic that needs to be actually mapped. For example, morainal* deposits (M) are typically very compact and consist of stones set in a mixture sand, silt and clay. Lacustrine* deposits (L) are generally fine-textured (silt and clay) and commonly give rise to unstable slopes. The various types of surficial materials that were mapped in the East Kootenay region are listed and defined in Appendix B.2, and described in Chapters Four to Eight.

Process status descriptors, "active" and "inactive", are used to indicate whether or not deposition of surficial material is taking place at the present time (Appendix B.6). In order to minimize the number of letters in the terrain unit symbol, each type of material is assumed to be either "active" or "inactive", and this status is indicated in the "genetic materials" column of the map legend. A process status descriptor is then shown in the terrain unit symbol only if the current state of the material is contrary to the assumed state. For example, fluvial materials (F) are designated "inactive" in the map legend. Consequently, a floodplain that is periodically inundated would be mapped as F^A, whereas relict fluvial materials, such as those in terraces that are far above the reach of floodwaters, would be mapped as F.

3.2.2 MATERIAL TEXTURE

Texture refers to the shape and size characteristics of sedimentary particles (of all sizes), and their grain to grain interrelationships. This is an extremely important characteristic of sediments, since it directly influences other basic properties such as porosity and permeability, rates of groundwater flow, drainage, cohesion, compactibility and susceptibility to erosion. Texture is a function of the nature of the bedrock from which the material was originally eroded, and the mode and distance of transportation and mode of deposition that the particles have undergone. Thus texture can often be inferred after the genesis of the material has been determined by aerial photograph interpretation, and confirmed later, where possible, by ground checking. Textural terms used for terrain mapping in the East Kootenay are defined in Appendix B.3.

Particle sizes are classified after the Wentworth grade scale, which defines terms such as clay, silt, sand and boulders within specific size limits (Wentworth, 1922).

Sorting refers to the range of particle sizes within a sediment, or the "particle-size distribution". Thus a "well-sorted" deposit contains only a narrow range of particle sizes, whereas a "poorly-sorted" or "non-sorted" deposit contains particles of a great variety of sizes[1]. Diamicton (d) is a mixture of particles of various sizes, and contains both fines (silt and/or clay) and coarse particles. It is thus non-sorted by definition. Normally the use of one textural term, such as silt (\$) or gravel (g), implies that the material is relatively well-sorted. The use of two textural terms, for example silty sand (\$s) or sandy gravel (sg) implies a greater range of particle sizes. These materials would contain approximately:

silty sand	20-50% silt, 50-80% sand
sandy gravel	20-50% sand, 50-80% gravel

Obviously, there are many relatively poorly-sorted materials which cannot be totally described by this system.

Sorting is controlled to a great extent by the mode of deposition of a sediment. For example, particles which settle from suspension in air (eolian) or water (lacustrine, some fluvial*) tend to be well-sorted. Glacial deposits (till) and most colluvial deposits (e.g. debris flows) are poorly-sorted or non-sorted.

Roundness refers to the roundness or angularity of the corners and edges of particles larger than sand grains. Boulders and particles in gravel are generally rounded or subrounded, whereas rubble and blocks are angular and sub-angular. The roundness of particles in a sedimentary deposit is related primarily to the distance they have been transported from their original bedrock source. Thus for example, fluvial deposits consist of particles that are generally rounded, and the degree of rounding may increase downstream.

3.2.3 LANDFORMS AND TOPOGRAPHY - "SURFACE EXPRESSION"

Land surface configuration is indicated in two ways on the terrain maps:

1. Maps are printed on a topographic base which has a contour interval of either 100 feet or 40 metres. Thus contours indicate all relief features with amplitude greater than this.

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[1] Note: The term "well-graded" as used by engineers is equivalent to poorly-sorted, and "poorly-graded" is equivalent to well-sorted.

2. Smaller topographic elements are referred to as "surface expression" under the Terrain Classification System. They are classified morphologically by using simple, objective criteria such as geometric shape, slope, and relationship to the configuration of underlying bedrock or older unconsolidated materials. Terms that are used to describe surface expression have no genetic implication. A definition of each term is given in Appendix B.4.

In addition to these two methods of showing topography, on-site symbols are used to represent specific landforms such as escarpments*, cirques* and drumlins*. Landform information is also supplied by the application of certain modifying process descriptors (see below), which indicate features such as gullies and kettles*.

3.2.4 MODIFICATION BY GEOLOGICAL PROCESSES - "MODIFYING PROCESSES"

Many landforms and surficial materials have been (or are being) altered or modified by geological processes other than those whereby they were formed. For example, a valleyside that was mantled with till* during glaciation may now be raked by avalanches or dissected by gullies; silts and clays originally deposited in ice-dammed lakes may now be susceptible to failure and collapse.

Some of these processes are occurring at the present time, although probably sporadically rather than continuously. Nevertheless the distribution of terrain units that they affect is of considerable importance, since many modifying processes constitute potential hazards to various kinds of land use (Chapter Nine). Modification of the land surface by certain geological processes that are no longer active is also indicated on terrain maps, since these processes commonly left behind significant features such as glacial meltwater channels* and kettle depressions.

The "active" or "inactive" status of a modifying process is indicated by, or can be inferred from, the terrain unit symbol in the same manner as status is shown for genetic materials. The various types of modifying processes and their "active" or "inactive" status are defined and described in Appendix B.5.

3.2.5 TERRAIN UNIT SYMBOLS

Characteristics of terrain within each terrain unit are indicated by a group (or groups) of letters. The position of each letter within a group represents a particular characteristic of terrain. (Letter symbols are defined in Figure 3.1 and Appendix B).

Examples of simple terrain units

material texture	genetic material	process status	surface expression	modifying process	process status	symbol as it appears on terrain map
g	F	A	l	-E	A	$gF^{A}l\text{-}E^{A}$
r	C		a	-A		rCa-A
	M		b			Mb
	L		t	-P		Lt-P
sg	F		t			sgFt
g	F	G	rh			$gF^{G}rh$
	I					I

Note that:

1. Genetic material and surface expression are shown for all terrain units except glaciers (I).
2. Omission of texture indicates lack of information. This implies that the terrain unit was not checked in the field and texture could not be reliably interpreted from aerial photographs.
3. The use of two textural terms indicates a mixture of particle sizes with the latter one predominating.
4. The use of two surface expression terms indicates that both are common within the terrain unit.

When viewing an unfamiliar terrain map for the first time, the reader should initially scan the area and note the genetic material symbols. This is the fastest way to obtain an overall impression of the characteristics of the terrain. Then, if the reader is interested in some specific aspect of surficial materials or geological processes, he/she should then search for particlar symbols. For example, terrain units containing gravel can be easily identified by glancing at the left-hand side of each terrain unit symbol in order to locate "g". Similarly, areas affected by avalanches can be picked out by scanning the right-hand side of each symbol to locate "-A" (modifying process).

Composite terrain units contain two or three different kinds of terrain, and consequently their terrain unit symbols contain two or three groups of letters.

Examples: gFt.sFl

Mb/Cb//Rs

The slashes or dots indicate the relative proportions of the two terrain components that they separate:-

. components on either side of the dot are approximately equal

/ the component in front of the slash is more extensive than the one that follows

// the component in front of the double slash is considerably more extensive than the one that follows

Examples: Mb/Cb//Rs - Mb is more extensive than Cb, and Cb is considerably more extensive than Rs.

gFt//Rs.\$Ls - gFt is considerably more extensive than Rs; Rs and \$Ls are approximately equal

Stratigraphic information is provided for some terrain units.

Examples: $\frac{sEv}{gFt}$ - sEv (veneer of eolian sand) overlies gFt (gravelly fluvial terrace)

$\frac{Mb}{gF^{G}}$ - Mb (morainal blanket) overlies gF^{G}(fluvioglacial gravels)

Modifying process symbols are placed at the end of a composite terrain unit symbol, no matter which component of the symbol is affected by the modifying process.

Example: rCa/Rs - A

3.2.6 ON-SITE SYMBOLS

On-site symbols are used to show the specific location of some types of landforms and other features of interest that cannot be accommodated by terrain units and terrain unit symbols. Some of these features, such as eskers (sand and gravel ridges), give additional information about the nature and distribution of surficial materials. The portrayal of features such as landslide scars is also of obvious practical importance.

Most on-site symbols indicate distinctive landforms that occupy areas that are too small or too narrow to be delimited as terrain units. Kettles, karst* depressions, escarpments, moraine ridges and landslide scars are significant features of this type.

On-site symbols are also utilized to indicate information about the glacial history of an area. Examples include ice-flow direction indicators (striae*, flutings*, crag and tail*, drumlins), abandoned shorelines*, cirques, and moraine ridges.

3.3 TERRAIN MAPPING PROCEDURE

Terrain mapping is carried out by aerial photograph interpretation supplemented by ground checking. The procedure involves several stages of office and field work.

3.3.1 PRELIMINARY CONSIDERATIONS

At the commencement of a project, basic decisions are made in order to relate the purpose and objectives of the project to the type and amount of information to be collected. Thus the appropriate mode of terrain classification, and the scale of aerial photographs, working maps, and final maps, are determined at the outset. Personnel and logistical arrangements are also planned at this time.

If any previous geological work has been done in the project area, the results are compiled and studied. Some prior knowledge of glacial and post-glacial history is particularly useful to the mapper, since this can be used to deduce the likely distribution of surficial materials.

3.3.2 PRELIMINARY INTERPRETATION OF AERIAL PHOTOGRAPHS

This is done in order to outline terrain units on the aerial photographs and to make an initial assessment of their characteristics. Particular landforms, vegetation patterns, tonal patterns, and photographic texture can be used to differentiate terrain units and interpreted to indicate the type(s) of surficial materials that occur within each terrain unit. Other characteristics, such as material texture, can also be tentatively inferred at this stage.

Where aerial photograph interpretation is judged to be unreliable, for example in areas of dense tree cover or ambiguous ground features, terrain units are selected for field checking. Areas that appear to be representative of various types of terrain and sites where surficial materials are well exposed, such as steep, high river banks, are also earmarked for ground investigation.

From a logistical point of view, aerial photographs are also examined to determine the extent of roads or other ground access, and to locate possible landing sites for helicopters during airborne surveys.

3.3.3 FIELD WORK

This involves checking and confirmation (or modification) of preliminary aerial photograph interpretation, and collection of additional data regarding the nature and distribution of surficial materials. Sites are examined where surficial materials outcrop extensively, such as riverbanks and road and railroad cuttings, in order to determine, as accurately as possible, the overall characteristics and variability of the surficial materials. Sites where several types of materials are superimposed are of particular interest, since their stratigraphy gives information about recent geological history of an area. This in turn leads to a better understanding of the distribution and character of surficial materials.

In addition to observations necessary for terrain mapping, information is collected about characteristics of surficial materials such as thickness, structure, compaction, lateral extent and variability. More detailed textural descriptions are also noted. This information is incorporated into the descriptions of materials that are given in Chapters Four to Eight.

In the East Kootenay region, two to four weeks of field work were done for each 1:50 000 scale mapsheet - an area of about 1000 km^2. This length of time varied in accordance with the density of the road network. Virtually all roads passable to four-wheel drive vehicles were traversed, but since there was relatively little access to higher mountain slopes, field checking was automatically concentrated along the valleys. In general, time was insufficient for foot traverses. Access to remote areas for spot-checking of selected terrain units was provided by helicopter. Airborne surveys were limited to an average of one day for each 1:50 000 scale map sheet.

3.3.4 OFFICE WORK FOLLOWING FIELD WORK

Terrain unit boundaries and symbols, and on-site symbols previously drawn on aerial photographs are reassessed, modified where necessary, and finalized with respect to information collected during field work (Plate 3.1). A legend is compiled for the terrain maps. It includes brief descriptions of salient characteristics of surficial materials in the project area.

Lines and symbols are then transferred from aerial photographs onto topographic base maps, and the maps are then drafted. At each step of this process the maps are checked by the original mapper in order to minimize mechanical errors.

3.4 QUALITY OF TERRAIN MAPPING

The accuracy and reliability of terrain mapping is difficult to assess in a general manner since terrain maps consist of several partially interrelated components and the process of terrain mapping involves many variables.

The components of a terrain map that can be assessed for accuracy include:

a. overall pattern of terrain units
b. position of terrain unit boundary lines
c. components of the terrain unit symbol
d. position and usage of on-site symbols

The overall pattern of terrain units is the mosaic of irregularly shaped areas that is drawn on aerial photographs and eventually transferred to the final map. In areas of simple terrain, where relatively large, uniform areas of each terrain type are separated by well-defined boundaries, the pattern of terrain units is clearly expressed. Independent mappers would likely delineate identical mosaics of terrain units. In areas of complex terrain, however, where small patches of various types of terrain are intermixed and grade one into the other, interpretation of aerial photographs is relatively difficult, and independent mappers would probably define a variety of patterns. Different combinations of terrain types would be selected as composite units, hence size of units and boundary positions could differ drastically. Although some ways of doing this would be better than others, in many cases several different patterns are equally acceptable and there is no single

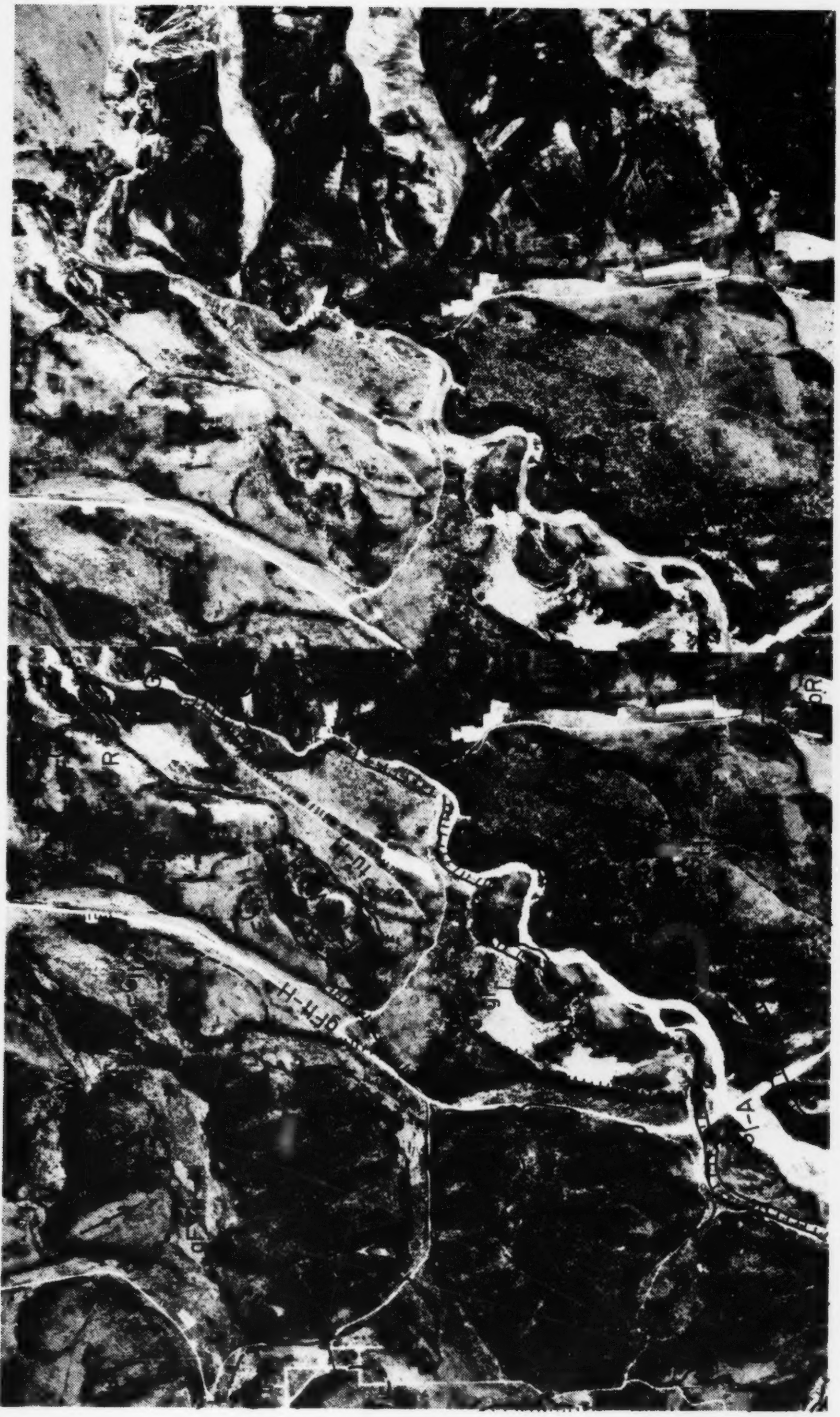

Plate 3.1 Example of interpreted aerial photograph for part of area shown in Figure 3.1. Province of British Columbia, B.C. 5491-103, 104.

correct solution. The final result will depend upon the judgement and style of an individual mapper.

The overall accuracy with which the remaining three components are portrayed on any particular terrain map depends primarily upon:

a. ability and experience of the mapper
b. scale and quality (definition, contrast) of air photos
c. nature of terrain
d. extent of dense vegetation cover or artificial disturbance of terrain (such as recent logging activity)
e. availability of field access
f. the number and extent of exposures of surficial materials
g. length of time spent in the field and number of sample sites

Other factors of less importance include:

h. availability and quality of previous work
j. accuracy of technical processes employed during preparation of final map

Consistency is one of the most important aspects that must be considered in any evaluation of terrain map reliability. The character and quality of terrain maps should be consistent throughout the project area. In a project such as this one, where terrain mapping is carried out by several individuals, special efforts must be made to ensure that all mappers are applying the terrain classification scheme in a similar manner, making comparable field observations and interpretations, and maintaining a uniformly high standard of mapping.

The amount of detail shown on a terrain map (e.g. the intricacy and size of terrain units; number of on-site symbols) is commonly confused with accuracy. However, intricate boundary lines are not necessarily in the correct position, and small terrain units may be incorrectly identified. The size of the smallest terrain units that are shown is, in fact, controlled by cartographic considerations, map scale, and decisions made during the preliminary stage of the project. In the East Kootenay area, the smallest terrain units have an area of about 0.1 km^2 or 162 hectares.

Bearing in mind the number of factors involved, it is possible to make only a few tentative comments on the quality of terrain mapping in the East Kootenay region. It is likely that mapping was carried out most accurately in those areas where a road network enabled much ground checking, such as on the floor of the Rocky Mountain Trench and parts of the Fernie Basin. Where a single road follows a valley floor in mountainous terrain, the terrain units that it traverses will have been checked.

Areas without ground access, however, are mapped solely from aerial photograph interpretation. The proportion of total units checked by helicopter surveys is so small that it has little effect on the overall quality of a map, although useful site specific information is collected. Aerial photograph interpretation is judged to be least reliable on densely forested valley sides, which constitute a large part of some map areas. Alpine areas above timberline present few problems for aerial photograph interpretation, and were probably mapped with a high degree of accuracy, despite restricted access.

Certain landforms and surficial materials, such as river terraces, alluvial fans*, and talus* slopes, have distinctive characteristics which are inherently easy to identify on aerial photographs. Others display variable or ambiguous features and gradational contacts with adjoining landforms and materials (e.g. colluvial and morainal blankets). Their delineation and designation by terrain unit symbols tends to be relatively unreliable. Further comments on this topic are given for individual landforms and materials in Chapters Four to Eight.

Chapter Four

Chapter Four

CHARACTERISTICS AND PROPERTIES OF MORAINAL MATERIALS (TILL) AND ASSOCIATED LANDFORMS

4.1 DEFINITION AND MODE OF FORMATION

Till* is deposited directly by glacier ice. It consists of material that was originally eroded from the bed of a glacier (either bedrock fragments or older surficial materials), and material deposited on a glacier surface by avalanches and rockfalls. Debris in the ice ranges from rock flour (clay and silt) to large blocks. It is transported by the glacier, and eventually deposited when melting occurs at the base of the ice (basal till), at the ice surface (ablation till), or at the glacier snout (end moraines).

The specific characteristics of till or morainal* deposits at any particular place will thus depend upon the provenance (original source) of glacial debris and its mode of deposition. Some distinctive kinds of till that occur within the East Kootenay region are described later in this chapter (section 4.4).

4.2 CHARACTERISTICS , ENGINEERING PROPERTIES AND LANDUSE IMPLICATIONS

Basal till is the common type of morainal deposit in this region. It consists of a mixture of clasts of various shapes, sizes and rock types set in a matrix of clay, silt and sand (Appendix C.). For example, till derived from lacustrine* and fluvial* deposits may consist of rounded pebbles in a silt-clay matrix (Plate 4.1); till deposited by ice flowing from limestone terrain consists of angular rock fragments in a gritty, silty matrix and is highly calcareous*.

Basal till is non-sorted and massive*. By comparison with other surficial materials, it is relatively compact, highly consolidated, and cohesive and hard when dry. Excavation of basal till with earth moving equipment may be diffcult, especially where it contains large boulders and blocks (aM, bM). Bearing strength* is relatively high; plasticity and compressibility are low (Appendix B.2).

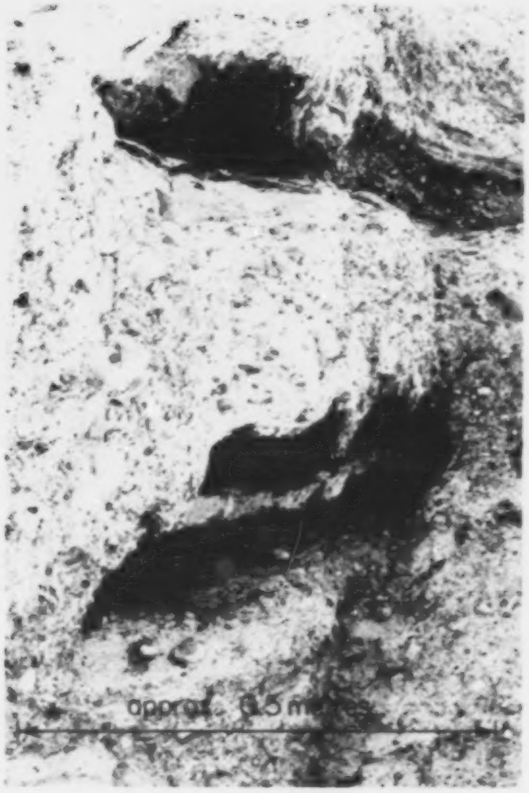

Plate 4.1 Wycliffe till near Dutch Creek: till consists of subrounded pebbles of many rock types set in matrix of sandy silt. Lenses of water-deposited, non-cohesive sand and fine gravel have been eroded by wind and nesting birds to form miniature caverns.

Tills with silt and clay in the matrix are porous,* but pore spaces are so small that the material as a whole is effectively impermeable*. Beds, lenses and tubes of gravel may be present within otherwise impermeable till, and may function as aquifers*.

Typically compact basal till is generally capped by a surface layer of loose, non-compact, weathered* till. This varies in thickness from a few centimetres to about two metres, in accordance with local moisture regime and site conditions. In moist areas, or during high moisture conditions such as spring snowmelt or prolonged rainstorms, the groundwater table commonly lies at, or slightly above, the interface between weathered and unweathered till. Movement of groundwater is relatively rapid along this interface and it may constitute a potential slip-plane for slope failure. Seepage along artificial excavations that intersect this zone commonly causes sloughing and upslope recession of cut banks. Silty and particularly clayey tills are also subject to deeper-seated slope failure* under high moisture conditions. Fine textured tills are susceptible to gully erosion and this, together with sheet erosion, may be provoked by removal of vegetative cover.

Ablation till is typically a loose, non-sorted and non-stratified, sandy, silty gravel. It contains much less silt and clay than basal till, since fines tend to have been washed away by meltwater*. As ice melts, ablation till slumps and slides on the glacier surface, and eventually is deposited as irregular hummocks and ridges (gMhr,sgMhr) or as a gravelly layer over basal till. Deposits of the former type are hard to distinguish from fluvioglacial* gravels (section 5.2) with which they commonly occur. The latter type of ablation till can only be identified from ground observation of sections. Consequently, ablation till is not normally shown as a distinct terrain component, but gravelly deposits may be expected to constitute a small proportion of many morainal units.

Further information regarding the capability of morainal materials to support residential settlement is presented in the East Kootenay soils bulletin. Equivalent soil association components and terrain units are listed in Appendix E.

4.3 TERRAIN UNITS

4.3.1 MANTLES OF MORAINAL MATERIAL (TILL) (Mv, Mb)

Basal till comprises several distinctive landforms or terrain units (Figure 4.1). It is commonly found along valley sides as a smooth mantle overlying bedrock or older Quaternary deposits. Where the till is relatively thin (less than 1m), it is mapped as Mv ("morainal veneer"). These terrain units may contain small areas of bedrock outcrop and colluvium, since thin till tends to be of variable thickness and irregular distribution. Thicker basal till is mapped as Mb ("morainal blanket") if its surface topography roughly conforms with topography on underlying bedrock or older unconsolidated material. Mb terrain is widespread along lower valleysides throughout the study area and over subdued mountainous topography in the Purcell Mountains to the east and southeast of Moyie Lake (Plate 4.2). In Mvb terrain units, till generally thins upslope.

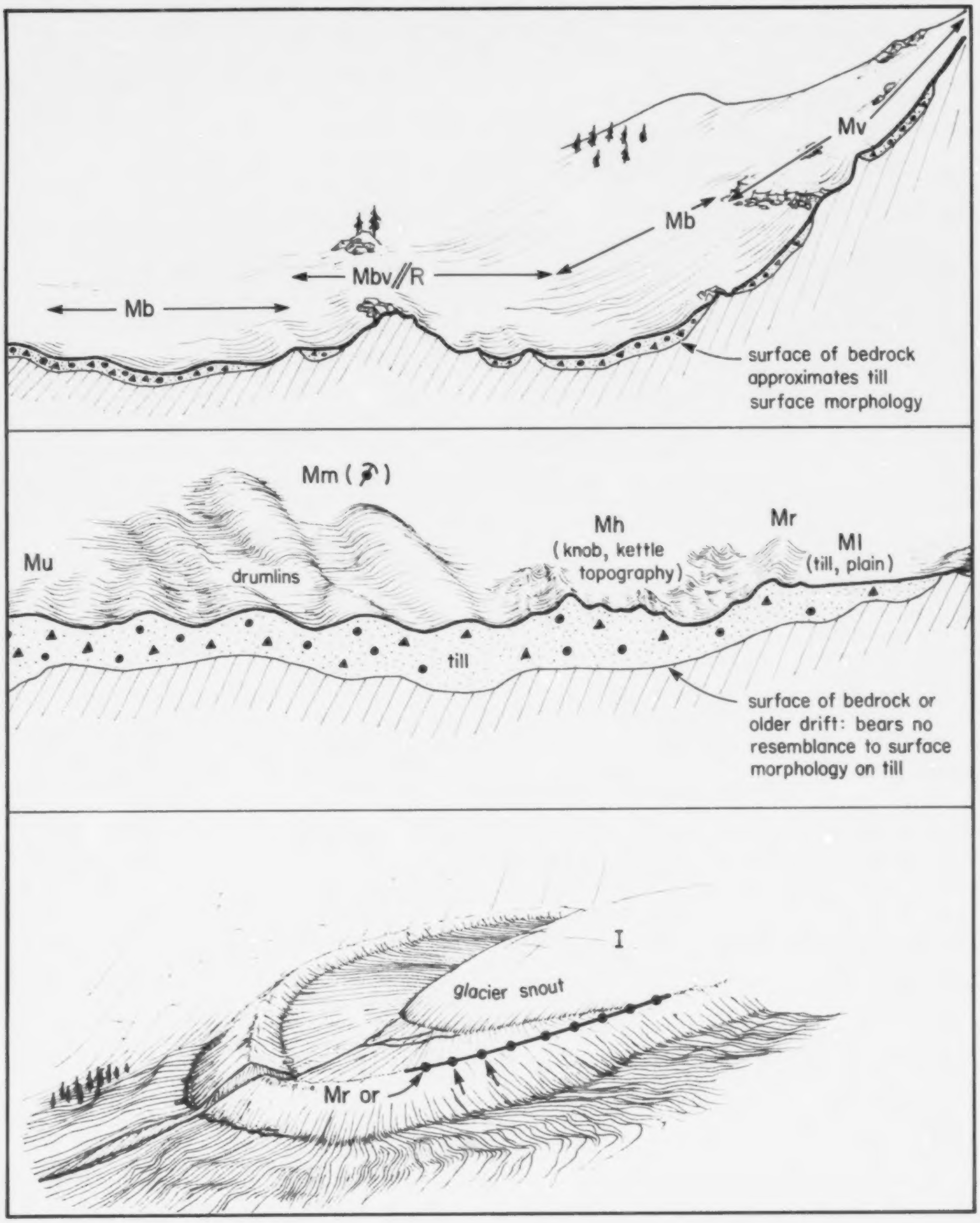
Mv
Mb
Mbv//R
Mb
surface of bedrock approximates till surface morphology
Mm ( )
Mh
(knob, kettle topography)
Mr
Ml
(till, plain)
Mu
drumlins
till
surface of bedrock or older drift: bears no resemblance to surface morphology on till
I
glacier snout
Mr or

Figure 4.1 Block diagrams to illustrate terrain units on morainal material (till)

Plate 4.2 View southward from Plumbob Mountain towards Gold Mountain (right), and Lake Koocanusa. This eastern margin of the Purcell Mountains rises gradually from the Rocky Mountain Trench. Forested slopes are mantled by till (Mb). Lakes in middle distance occupy a former meltwater channel.

4.3.2 GROUND MORAINE AND STREAMLINED MORAINAL TOPOGRAPHY (Mu, Mm, Mh, Ml)

Along the floors of major valleys and in other areas of subdued topography, basal till has been shaped by overriding ice to form constructional landforms (Figure 4.1). In areas of undulating ground moraine (Mu), slopes are gentle (less than 15°) and hills and depressions are randomly arranged. This type of terrain occupies large areas on the floor of the Trench, for example between St. Mary River and Ta Ta Creek (Plate 2.2), and the floor of Flathead Valley. Knob and kettle* morainal topography (Mh) is similar, but slopes are steeper and till may range from compact basal to loose ablation types. Till plains (Ml) are not common in this region. Streamlined morainal topography formed beneath the ice where till was moulded by the forward movement of a glacier. Resulting landforms range from faint flutings* or shallow grooves*, which are barely discernable on the ground, to well defined drumlins*. These forms are generally mapped by using a combination of letter symbols (Mm) and on-site symbols for flutings and drumlins. Good examples of fluted morainal topography and drumlins are found in the Rocky Mountain Trench south of Elk River.

4.3.3 MORAINAL RIDGES, END MORAINES (Mr)

Morainal ridges that mark the former positions of glacier termini are limited to alpine areas in the Rocky Mountains. They occur near present day alpine glaciers and indicate their recent Neoglacial* maximum extent (Plate 2.5). These end moraines are prominent, vegetation-free, sharp-crested ridges of rubble and blocks (rMr,aMr).

4.4 REGIONAL CLASSIFICATION OF TILLS

Several types of till may be distinguished within the East Kootenay region as a result of provenance within differing geological (physiographic) regions; (see also Appendix C.1).

Wycliffe Till was first defined ("Wycliffe drift") by Schofield (1915) and later mapped and described by Kelley and Sprout (1956), Kelley and Holland (1961) and Clague (1973). It occupies the floor and lower side slopes of the Rocky Mountain Trench, and consists partially of older unconsolidated materials reworked from the Trench floor, and partially of glacial debris from tributary valleys.

Wycliffe till is a massive, non-sorted mixture of clay, silt and sand with coarse fragments that vary widely in size but consist chiefly of pebbles and cobbles. Typical matrix composition is 30-40% sand, 30-40% silt and 20-30% clay. The proportion of clay and silt particles increases near the base of the till due to incorporation of underlying lacustrine sediments. Clasts make up about 15 to 25% of the till by volume. They are subangular to subrounded, commonly striated*, and consist of a variety of rock types that are present in the adjacent Rocky and Purcell Mountains. The till is compact where unmodified by weathering, cemented and hard when dry, and slightly plastic when wet. Colour[1] varies from light grey to very light grey in dry exposures. Till on the Trench floor is typically between 10 and 30 m in thickness. Lenses of water-worked sand and gravel occur within the till sheet, and lacustrine silts 3 to 15 m thick occur within the till along the sides of the Trench (Clague, 1973).

Till in the Trench is strongly calcareous, but it grades westward into either less calcareous or non-calcareous (but otherwise similar) till derived from the Purcell Mountains.

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[1] Colours are described according to Munsell soil colour charts (Munsell, 1954).

The Wycliffe till sheet was deposited over most of the Trench floor during Faser Glaciation. During ice recession, it was dissected by meltwater channels, as for example in the Tobacco Plains area (Figure 2.2). Further entrenchment of rivers has occurred in postglacial time. Wycliffe till is exposed in vertical bluffs along Elk, St. Mary, and Lussier Rivers and along other tributaries of Kootenay River.

Cedrus Till was first recognized and mapped by Kelley and Sprout (1956) in the Kootenay River valley north of Canal Flats. It is distinguished by its provenance from calcareous phyllites* and shales of the Upper Cambrian-Ordovician McKay Group. These rocks occupy a major shear zone along Kootenay-White valley between Kootenay Crossing and White Swan Lake (Henderson, 1954). Similar rock types and consequently similar till underlie other longitudinal valleys* further east, such as those of North White - Queen Mary Creek and Upper White River. Intervening ridges consist of limestone* and dolomite*.

Typical Cedrus till is found directly overlying phyllite bedrock. It is a massive, clayey silt with few coarse fragments and is typically composed of 10-30% sand, 40-60% silt and 20-40% clay (see Appendix C.1). Clasts make up 0 to 15% of the volume of the till and are chiefly phyllite and limestone pebbles. Weathered phyllite clasts are common, but since they disintegrate to fines when disturbed, they were not counted as coarse fragments.

Cedrus till is soft and non-compact, although it tends to stand in vertical faces in fresh cuts due to cohesion between particles. It may be slightly more plastic than most other tills of the region (Appendix C.2). It is porous, but relatively impervious*, and strongly calcareous. In colour, Cedrus till is generally very pale grey and may show an overall greenish tinge which is derived from the colour of the parent rock. The original phyllite has a schistose* texture and contains particles of calcium carbonate, quartz, chlorite*, and minor amounts of sericite* (Henderson, 1954). Particles of these minerals probably constitute most Cedrus till. Washed till surfaces may have a slight lustre, due no doubt to a covering of schisty particles.

In Kootenay-White valley, till thickness ranges from less than one metre over low bedrock rises on the valley floor to a maximum observed thickness of 20 m in the banks of White River. Till is widespread along the floor and sides of this valley ($Mv, $Mb and $Mu). Similar terrain along North White and Upper White Rivers probably also consists of Cedrus till.

Local varieties of Cedrus till occur within White and Kootenay valleys and within adjacent transverse valleys*. In places, for example near the Kootenay-White confluence, till is at least partially derived from older Quaternary sediments. It is sandier (sandy silt matrix), stonier, and more compact than typical Cedrus till; coarse fragments comprise 20-40% of the total volume, and consist of limestone, phyllite, shale, sandstone, and minor quartzite* and argillite*. Cedrus till also grades upslope into increasingly stony tills with subangular and angular clasts of limestone, dolomite, and shale: coarse fragment contents of up to 90% were observed. Pockets and lenses of fluvial gravel occur here and there in these valleyside till sheets. Compact silty tills with limestone clasts are present on gentler slopes in transverse valleys.

Elk Valley Tills are a distinctive suite of tills that occur on shale, sandstone and coal of the Jurassic-Cretaceous Fernie Group and Kootenay Formation in the Fernie Basin. Till derived from shale closely resembles the parent rock, to the extent that "weathered rock" and "till" are hard to distinguish both on aerial photographs and on the ground. At valley sites on Fernie shale, till matrix generally contains a high proportion of silt: three samples analysed consisted of 20-30% sand, 50-60% silt and 10-20% clay. Tills with higher clay content (clayey silt) occur locally. Atterberg limits determined for a few samples of till from this area indicate that some of the fine textured till in Elk valley may be the most unstable (when moist) of all tills in the East Kootenay region (Appendix C.2). Sandy tills are associated with sandstone and conglomerate of the Kootenay Formation which tend to outcrop on higher ground such as Horseshoe Ridge. Till colour varies through yellow, grey, and black, depending upon the parent rock.

Kelley and Sprout (1956) distinguished two tills in Elk Valley and on adjacent ridgecrests. Hosmer Clay Loam (till) is derived from soft, yellowish-brown to black shales. It contains varying proportions of clasts of black shale and coal and sufficient limestone to make it calcareous. Cokato clay loam (till) is derived from partially decomposed yellow and black shales and soft sandstone, and contains shaley boulders and scattered stones of quartzite and argillite. It is less compact than other local tills and non-calcareous.

Flathead Till constitutes extensive areas of gently undulating and rolling terrain on the floor of the Flathead Valley (Mum). It is a pale-grey, moderately stony till with a matrix of silty sand or sandy silt. One sample analysed gave 47% sand, 31% silt and 22% clay (Appendix C.1). Clasts consist of a mixture of rock types derived from adjacent mountains. The till is strongly calcareous, except adjacent to outcrops of non-calcareous bedrock such as shale and argillite. It is generally similar to Wycliffe till, and was probably also derived chiefly from older Quaternary sediments.

Sandy, stoney Purcell Till is widespread on uplands in the Yahk Range and adjacent areas of the southern McGillivray Range (sMb, sMv). One matrix sample analysed gave 44% sand, 47% silt and 9% clay (Appendix C.1). It contains a high (up to 70%) proportion of coarse fragments, and in some places, a high proportion of boulders (bsMb). This area is underlain by argillaceous quartzites and quartzites of the Creston and Aldridge Formations (Schofield, 1915). The sandy till is probably derived partly from these rocks and partly from intrusive igneous rocks* which outcrop to the northwest and were crossed by ice that overrode the Yahk and southern McGillivray Ranges. Pockets of very gravelly material may be ablation till.

Silty till prevails on the same bedrock in uplands adjacent to Moyie Lake and Lamb Creek ($Mb, $Mv). Its matrix typically consists of 25-35% sand, 50-60% silt and 10-20% clay. This till is otherwise similar to Wycliffe till, although it is less calcareous or non-calcareous. It may have been deposited by that part of the southerly flowing Trench glacier that was deflected into the Purcell Mountains south of Cranbrook by the northern tip of the McGillivray Range.

Specific types of till were not defined for the remaining parts of the study area. In general, till texture reflects texture (particle or crystal size) of underlying or up-glacier bedrock. Limestone, dolomite, argillite and phyllite tend to give rise to silty tills, shale, mudstone, and siltstone produce clayey silty tills, and sandstones and conglomerates form sandy tills. Coarse-crystalline igneous rocks also produce sandy tills. Two striking examples occur in the Hughes Range: the White Creek batholith* of quartz monzonite* has given rise to a small area of sandy till (too small to be mapped) at the head of Wild Horse River; several sMb terrain units, about six kilometres south of Summer Lake, reflect a small granodiorite* intrusion.

Chapter Five

Chapter Five

CHARACTERISTICS AND PROPERTIES OF FLUVIAL AND FLUVIOGLACIAL MATERIALS AND ASSOCIATED LANDFORMS

5.1 DEFINITION AND MODE OF FORMATION

Fluvial* materials result from deposition by streams and rivers. Fluvioglacial* materials result from deposition by glacial meltwater* streams, either in contact with a glacier, or a short distance downstream from an ice front. All fluvioglacial units shown on terrain maps contain materials that were deposited during recession of the final phase of Fraser Glaciation*. All fluvial units contain materials that were deposited during postglacial time, and deposition still continues, sporadically, along some "active" creeks and rivers. Older fluvial and fluvioglacial materials underlie Fraser drift* along parts of some major valleys.

Flowing water transports sediment in three ways. Suspended load typically consists of fine sand, silt, and clay particles that are kept in suspension by the turbulence of flowing water. Bedload normally consists of sand, pebbles and larger particles that are rolled or bounced along the river bed due to the tractive force of flowing water. Material carried in a dissolved state (solution load) affects water quality, but has little effect on fluvial deposition. Total volume of sediment that can be transported by a river depends upon discharge, and size of the largest particles that can be carried depends upon flow velocity. Sediment load thus increases considerably during floods when both discharge and flow velocity increase. Particles are picked-up from bed and banks during rising water, and redeposited further downstream as the floodwave passes. Similarly sized particles tend to be deposited more or less simultaneously, and so "sorted" sediments are formed.

Along the course of a river, deposition occurs where sediment load exceeds the transporting capability of flowing water. This may result from excessive sediment supply, such as occurs where steep tributary creeks carry bouldery gravels into a large, but slow flowing river. It also occurs where there is a decrease of stream gradient, and hence velocity, or where a constricted channel, such as a bedrock gorge, emerges into an unconstricted area and becomes relatively broad and shallow. Conversely, erosion will occur where streams have a greater transporting capacity than is actually utilized by sediment load supplied from upstream. This commonly takes place where a channel gradient is relatively steep (and flow velocity high), such as downstream from the threshold of a hanging valley.

The character of any given river and its associated fluvial sediments is controlled by a complex set of variables of which the most important are discharge (including hydrologic regime*), and sediment load (total volume and particle sizes) supplied from tributary streams and valley-sides. For example, streams that transport much bedload (sand and gravel) tend to develop wide, shallow channels with bars that represent temporary storage of in-transit material between floods. Elk River is an example of this type. Braided* streams on broad gravel floodplains* result from abundant bedload supply and fluctuating discharge, and may indicate areas of gravel accumulation. Most glacial meltwater streams are of this type, since glaciers provide a large supply of debris. Reduction of gradient also leads to localized deposition and development of a braided channel pattern. The Kootenay River displays this characteristic at Canal Flats where it emerges from mountains into the Trench. A broad gravel fan (now a terrace) near the mouth of Lussier River formed similarly, shortly after deglaciation.

By way of contrast, rivers carrying chiefly suspended load tend to occupy relatively deep, meandering* channels. Deposition occurs on the inside of meander beds (point bars) where current velocities are low, while erosion occurs on the outer (undercut) bank. Fine sediment from suspended load is also deposited on the floodplain when it is inundated (overbank sediments). Kootenay River displays these characteristics near Wasa and again for several kilometres north of Bull River.

In general, gravel deposition (fluvioglacial outwash*) occurred along many rivers during deglaciation and early postglacial time. It was probably induced by the supply of glacial material to streams and rivers. As this gradually declined, erosion commenced along the river courses, leaving older fluvial materials as terraces and dissected fans.

5.2 CHARACTERISTICS , ENGINEERING PROPERTIES AND LANDUSE IMPLICATIONS

Fluvial materials consist of bedded and sorted gravel, sand, and silt. Particle size ranges up to boulders, and clasts are generally well rounded. Bedding and stratification are usually clearly defined in fluvial sediments, and consist of alternating beds of relatively finer and coarser material. Gravel beds are commonly separated by thin layers of sand. Bedding may be either horizontal or dipping (cross-bedding). Deltaic gravels occur as topset (horizontal) beds overlying foreset (dipping) beds. Fluvial gravels may be capped by up to 2 m of overbank sediments consisting of thinly bedded, horizontal fine sand and silt. In general, texture of fluvial sediments will vary with gradient of the depositing stream. Cobble and boulder gravels occur along steep mountain creeks. Fine gravels, sands and silts occur along low-gradient channels.

Fluvioglacial materials typically consist of gravels and sands that are characterized by their variability. This reflects the general instability of the proglacial* environment, including rapid fluctuations in discharge and sediment load of meltwater streams, and changing positions of ice-front and outlet streams. Outbursts of glacier-dammed lakes (jökulhlaups) cause occasional catastrophic floods which result in drastic shifts of channels and deposition of much heterogeneous debris.

The resulting fluvioglacial sediments range in texture from silt and fine sand deposited under low flow conditions, to massive boulder beds resulting from major floods. Abrupt variations of texture are typical. The materials may be sorted or non-sorted, bedded or massive, and scour and fill structures are common. Horizontal bedding or cross-bedding (Plate 5.1) may be present. Gravels typically contain a sandy matrix, but open pore spaces, or pore spaces filled by washed in silt are also common. Beds, lenses, or larger bodies of silt may also be present where meltwater was locally ponded. Layers of till formed by flowage of saturated supraglacial debris ("flow till") may be interbedded with fluvioglacial sands or gravels. Fluvioglacial sediments deposited in contact with a glacier tend to slump and slide as supporting ice melts. This results in irregular or even hummocky surfaces on landforms, and faults, veins and distorted bedding within the sediments.

Fluvial and fluvioglacial sands and gravels are highly porous* and permeable*. They generally constitute relatively dry and well drained sites unless the watertable lies close to the surface (section 5.3.1). Groundwater flow through sands and gravels, particularly well-sorted sands and gravels, is rapid. These materials are thus potential aquifers* and groundwater reservoirs. For example, groundwater is commonly present within outwash deposits where sands and gravels overlie relatively impermeable* drift or bedrock in old, infilled channels. Sands and gravels buried by younger drift are also a potential source of water.

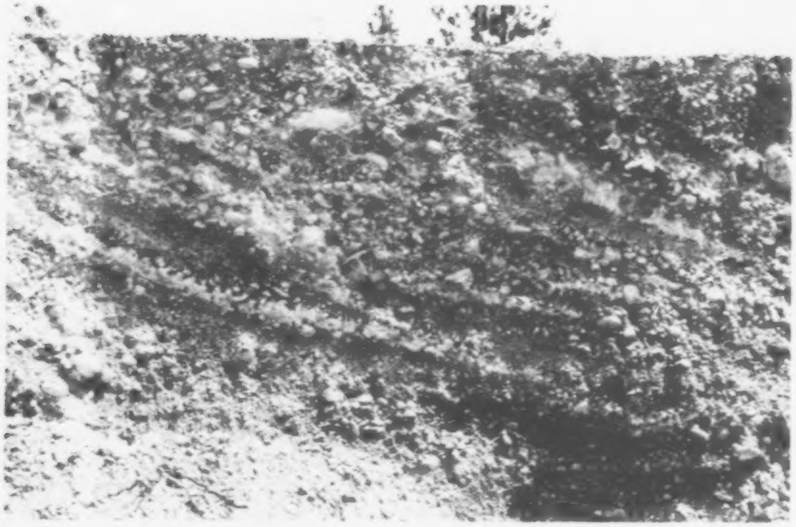


Plate 5.1 Fluvioglacial material near Canal Flats consists of cross-bedded, poorly-sorted gravels. Some beds have large, open pore spaces, others contain a matrix of sand or silt.

Fluvial sands and gravels and silt-free fluvioglacial materials are typically loose, non-cohesive and non-consolidated, although they may be weakly cemented (indurated) near the ground surface due to pedogenic* processes or locally at seepage sites due to precipitation of minerals from groundwater. Fluvial materials are thus subject to dry ravel along cutbanks, with slopes eventually receding to an angle of repose* of about 30°. Gravel slopes such as terrace scarps are not usually susceptible to deep-seated failure unless gravels are underlain by fine textured slide-prone materials such as lacustrine* silt (Chapter Six). Cutbanks in sandy or silty materials and vegetation-free areas may be modified by deflation (wind erosion) and dunes may form on leeward sites (Chapter Eight). Bearing strength* of well-drained and coarse textured fluvial deposits (gravels, sandy gravels) is high, although the strength of relatively thin terrace cappings (section 4.3.2) will depend in part on the nature of the underlying materials.

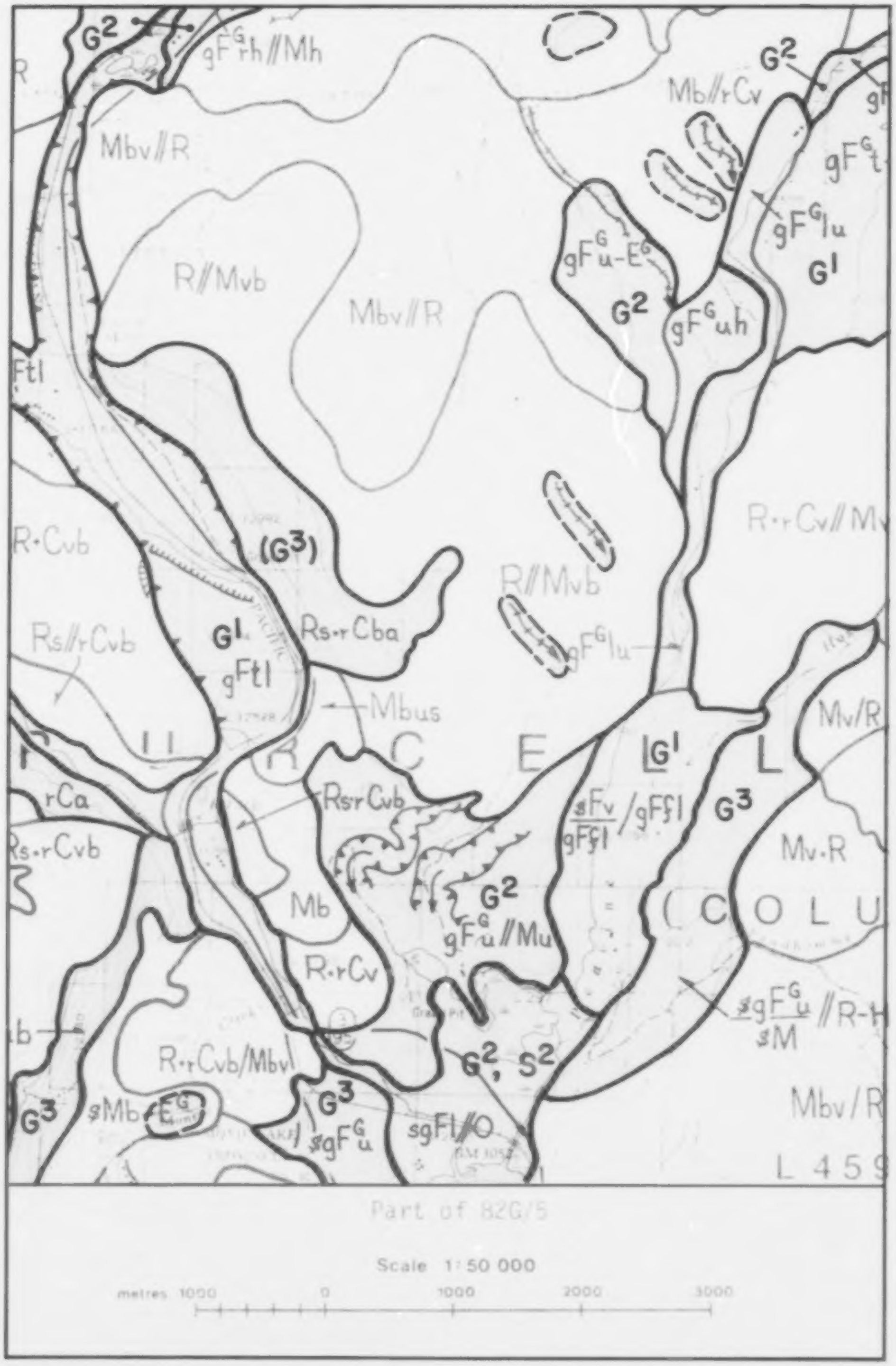
Further information regarding the capability of fluvial materials to support residential settlement is provided in the East Kootenay soils bulletin. Equivalent terrain units and soil associations are listed in Appendix E.

5.2.1 GRANULAR RESOURCES

Fluvial and fluvioglacial gravels and sands are the prime source of aggregate material. Terrain maps can be utilized for a preliminary assessment of potential granular resources. The general extent of these materials can be delimited on the map, and genesis of material, its texture (if indicated) and other attributes of a terrain unit can be interpreted to give some indication of the quality of aggregate. However, the map indicates no information about some important properties of aggregate material such as hardness*, porosity, or degree of weathering* of gravel particles, or total thickness of aggregate material. These considerations, together with aspects of quality of the basic 1:50 000 scale terrain maps discussed previously (section 3.4), imply that any derived map of aggregate resources should be considered only a guide to areas where more detailed investigations should be carried out.

A derivative map can be prepared from a terrain map by identifying (colouring or numbering) all sand and gravel bearing terrain units (Figure 5.1). All fluvial and fluvioglacial (F and F^G) units should be included, and any others where sand or gravel texture is indicated. Eolian* (sEb and dunes - Chapter Eight) and sandy lacustrine (sL - Chapter Six) materials are an additional source of fine aggregate. Colluvial* materials (Ca - Chapter Seven) may provide coarse aggregate where fluvial materials are absent.

A rough guide to the suitability for aggregate of material in some commonly occurring terrain units is given in Table 5.1. Materials are rated lower if they are likely to contain fines (silt, clay) or boulders, and if they characteristically show abrupt changes of texture, thickness or other characteristics. In general, fluvial deposits are rated higher than fluvioglacial deposits due to the tendancy of the latter to contain interstitial silts or pockets of silt, till, or boulders. Yet many ice-contact deposits such as eskers* and kames* (gF^Gr, gF^Gh - section 5.3.5) are useful sources of sand and gravel, particularly where they occur in upland areas distant from more extensive fluvial deposits in major valleys.


G^2
$gF^G rh//Mh$
R
Mbv//R
R//Mvb
Mbv//R
Mb//rCv
G^2
gF
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$gF^G lu$
G^1
$gF^G u-E^G$
G^2
$gF^G uh$
Ftl
R·Cvb
(G^3)
R·rCv// Mv
R//Mvb
G^1
Rs·rCba
Rs//rCvb
gFtl
$gF^G lu$
Mbus
Mv/R
U R C E L
LG^1
L
rCa
Rs·rCvb
Rs·rCvb
$\frac{sFv}{gFfl}$/gFfl
G^3
Mv·R
G^2
Mb
$gF^G u//Mu$
(C O L U
R·rCv
$\frac{sgF^G u}{sM}$//R-H
b
R·rCvb/Mbv
G^2, S^2
G^3
$sMb-E^G$
G^3
$sgF^G u$
sgFl//O
Mbv/R
L 459
Part of 82G/5
Scale 1:50 000
metres 1000
0
1000
2000
3000

Figure 5.1 Example of derivative map for aggregate resources and legend.

LEGEND

Rating	Coarse Aggregate	Fine Aggregate
Good	G^1	S^1
Moderate	G^2	S^2
Other possible sources	G^3	S^3
Parenthesis e.g. (G^3) indicate that the granular material constitutes a minor part of a composite terrain unit.		
Dashed lines indicate additional features which may contain granular materials.		

Notes:

(1) Veneers are ignored since they constitute an overburden less than 1 m thick.

(2) Parenthesis can be used as above, or units with a minor proportion of granular material can be omitted. Additional modifications can be made to suit the needs of each individual user.

TABLE 5.1:

TERRAIN UNITS AS POTENTIAL AGGREGATE SOURCES

Rating as Potential Source	Coarse Aggregate	Fine Aggregate
good	gFt, gFl, gFf (large), $gF^{G}l$, $gF^{G}r$, $gF^{G}t$	sFt, sFl, sFf, $sF^{G}l$, other SF^{G} units, dunes (on-site symbol), sEb
moderate	gFf (small), $gF^{G}h,m,u$, sgF, sg^{F}	sL, sgF, gsF gsF^{G}
other possible sources	bFf, bFl, $bF^{G}l$, Ff (small), rCa, rCf, meltwater channels ($-E^{G}$ and on-site symbols)	gFt etc., gF^{G} etc.

5.3 TERRAIN UNITS

Fluvial sediments constitute a series of well defined landforms such as terraces, fans and floodplains, that can be recognized fairly easily on aerial photographs. Difficulties arise only where features are small and masked by forest cover, or where natural boundaries are gradational, as at the toe of an alluvial fan*. Mapping of fluvial terrain units is considered to be relatively reliable. Fluvioglacial sediments may constitute distinctive, easily recognizable landforms such as eskers (section 5.3.5), but they also occur in irregular forms and patterns, and in many places, they are intermixed or closely juxtaposed with other late-glacial sediments such as till or lacustrine silt. Consequently, fluvioglacial deposits are commonly mapped in composite terrain units, and even "pure" fluvioglacial terrain units may contain heterogeneous materials.

5.3.1 FLOODPLAINS AND OTHER ALLUVIAL PLAINS ($F^{A}l$, Fl, $-E^{A}$)

These are areas of flat or very gently sloping land underlain by fluvial gravel, sand, or silt. Floodplains are subject to inundation from time to time ($F^{A}l$) or flooding due to shifting river channels ($-E^{A}$). They are poorly drained areas with high water table and possibly standing water for part of each year. Alluvial plains (F1) are relict floodplains that display no evidence of fluvial activity under present conditions.

Floodplains ($F^{A}1$) are mapped where flat land adjacent to a river shows some evidence or likelihood of periodic flooding. This includes distinctive vegetation, or lack of any vegetation or soil development, recently deposited sediment (or organic debris), cumulic* soil horizons, or simply high water table (poorly drained land) and elevation close to river level. Floodplains with shifting channels ($F^{A}1-E^{A}$) are shown where there are fresh channel scars, "cut-off" meanders, or scroll patterns* on the floodplain, and where rivers or streams presently occupy a braided channel system (Plate 5.2). Channel migration in such areas may occur suddenly during high flows, or gradually and systematically by bank erosion along the outer side of meanders or other curving channels.

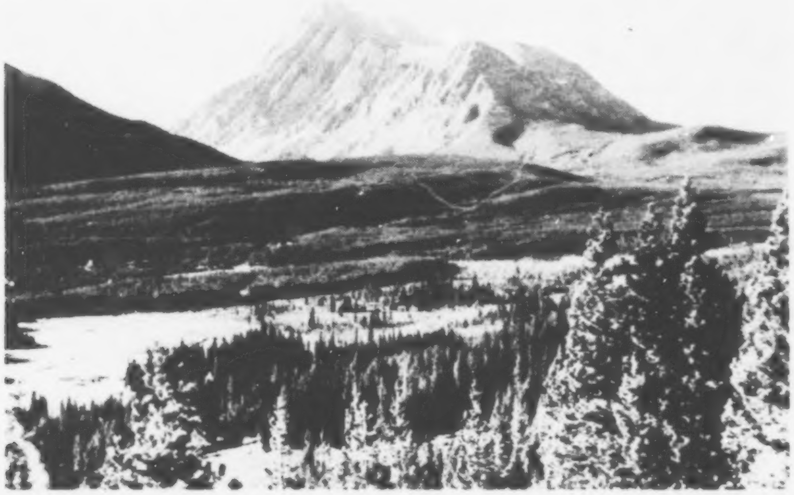

Plate 5.2 View northwestward across Elk River valley near Cadorna Creek. Elk River occupies a braided channel on a broad gravel floodplain. Floodplain vegetation in various stages of growth indicates that channels shift from time to time.

Alluvial plains (F1) along watercourses show no signs of recent flooding, but would possibly be inundated under unusual circumstances such as an extreme (100 year return period) rainstorm, or snowmelt, or channel blockage or diversion by mudflows, avalanches, log jams or similar means.

Fluvial activity (floods, sediment deposition) may be induced on formerly "inactive" floodplains if poor management practise during logging or other activities permits slope erosion and transfer of sediment to streams or increased surface runoff. River terraces (Ft) that lie close to river level may be similarly affected.

Some alluvial plains are the distal parts of old outwash plains (Plate 5.3). They carry no surface drainage under present day conditions, although groundwater may be present if thick sands and gravels are underlain by till or other impermeable stratum.

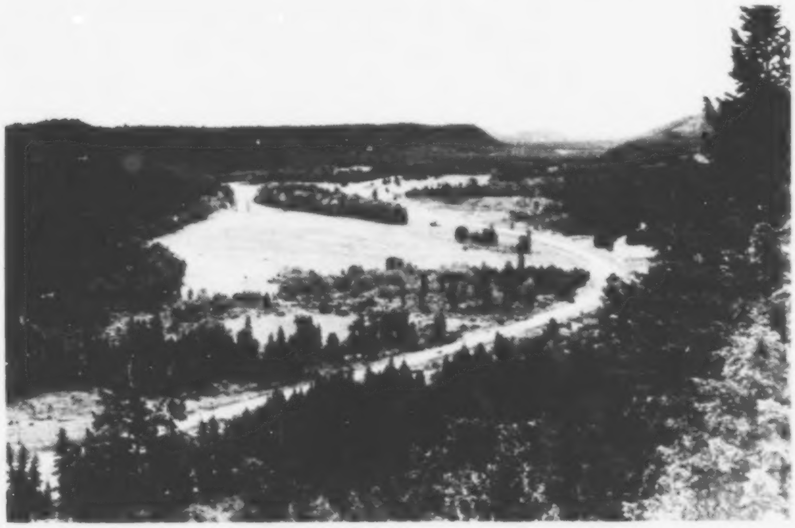

Plate 5.3 View northwards along Highway 93 near Roosville. This shallow valley is a meltwater channel that was followed by Elk River drainage during deglaciation. Valley floor is an outwash plain underlain by gravels ($gF^{G}l$ or gFl).

No long term records of floods or stream discharge were used in the preparation of terrain maps. Each terrain unit is described solely on the basis of field observations and/or aerial photograph interpretation. Qualitative judgements regarding distinctions between active and inactive floodplains and low terraces were made by individual mappers. Consequently, it is stressed that terrain maps should be interpreted conservatively for landuse (especially settlement) planning purposes (see also section 9.6). Further studies of river hydrology and morphology should be carried out in specific areas where any development or construction is planned.

5.3.2 RIVER TERRACES (Ft, Fs)

These are flat or slightly irregular surfaces bounded by scarps on the downslope side. Terrace surfaces may have a local relief of 1-2 m where old channels are present (Ft-E). Scarps may range in height from one to over one hundred metres, and slopes range from 20 to 35° on unconsolidated materials, and are steeper on bedrock. The scarp on-site symbol or the terrain unit symbols "Fs" or "Us" may be used to designate major scarps.

Terraces are typically underlain by gravels or sandy gravels that range in thickness from less than a metre to about 15 m. In some places, overbank silt or sand forms a fine textured capping over the gravel. Terrace surfaces along major valleys are commonly mantled by eolian silt or sand (Chapter Eight) or thin fluvial fans. Terrace materials overlie older Quaternary deposits (chiefly till, lacustrine silt or fluvioglacial gravels) or bedrock. Certain characteristics of the terrace, especially drainage conditions and bearing strength, will depend upon the nature of the underlying material and the thickness of the gravel capping. For example, fluvial terraces are normally well drained areas, but pockets of poorly drained land may occur where impermeable drift or bedrock lies at shallow depth beneath the terrace surface.

5.3.3 ALLUVIAL (FLUVIAL) FANS (Ff, F^Af, $-E^A$)

These are accumulations of fluvial material that in plan view are shaped like a fan, or in three dimensions, like a sector of a low-angle cone. They are located along breaks of slope where mountain streams debouch into broad, flat-floored valleys. Decrease in stream gradient, and broadening and shallowing of the stream channel as it emerges from the mountains leads to sediment deposition and development of braided stream channels across a fan. Good examples of alluvial fans are located where Windermere, Tatley and Dutch Creeks emerge into the Rocky Mountain Trench. Canal Flats is located on the fan of Kootenay River, and Elkford on the fan of Boivin Creek.

Large alluvial fans generally consist of stratified and well-sorted gravels and sands. Material is coarsest at the fan apex and becomes gradually finer towards the fan toe where thinly bedded sands and silts may occur. Surface gradients similarly decline from 6° to 10° near the fan apex to 2 to 3° at the fan toe.

Smaller alluvial fans, such as those along the foot of the western scarp of the Galton Range, emerge from small steep basins. Their sediments are relatively coarse and may include a high proportion of debris flow deposits. Gradients range up to about 15°. A complete gradation exists between large, low-gradient fluvial fans and small, steep debris-flow fans. The latter are generally mapped as colluvium (Cf, section 7.7). In general usage, the term "alluvial fan" refers to the entire range of fluvial and debris-flow fans.

A fluvial fan may be regarded as one particular type of floodplain, and so many of the comments made earlier (section 5.3.1) also apply here. "Active fans" ($F^{A}f$, $Ff\text{-}E^{A}$) are those where floods, shifting of channels, and sand and gravel deposition are likely to occur at the present time. Their streams are not incised below the fan surface, channels are braided, and vegetation patterns indicate the presence of abandoned channels and areas of recent deposition. Dutch Creek fan is an example of this type. Recent floods may have constructed torrent levées or left woody debris alongside channels. Just as floodplain modification can be induced by changes in hydrologic conditions in the drainage basin, so alluvial fans may be modified. In particular, increased runoff and sediment yield from a basin would probably result in changes in the position of stream channels on a fan. "Active fans" should be treated circumspectly in landuse planning. The potential activity of other fans (Ff) with surface drainage channels should also be investigated.

Many fans which were formed in early postglacial time have been dissected by later stream downcutting. Their creeks now occupy gullies of several to over 100 m depth below the fan surface. These "dissected fans" (Ff, Ff-V), like river terraces, provide good sites for settlement and industrial development, and are potential sources of material for aggregate and fill.

5.3.4 GLACIAL OUTWASH DEPOSITS AND MELTWATER CHANNELS ($F^{G}l$, $F^{G}t$, $-E^{G}$, -H)

Outwash deposits are sands and gravels laid down by meltwater streams that drained away from the ice margin. They form level or gently sloping surfaces punctuated by kettle* depressions and ice-contact scarps. In narrow mountain valleys, the original outwash plains may have been dissected to form terraces ($F^{G}t$, $F^{G}t\text{-}H$). Although these are widely distributed, they have commonly been buried by younger alluvial fans or colluvium, or partially removed by gulley erosion, so that their extent on terrain maps is limited. In areas of low relief, such as the floor of the Rocky Mountain Trench, outwash deposits filled depressions between drift hills to form shallow sinuous channels with broad flat floors or low terraces ($F^{G}l$, $F^{G}l$-H, $F^{G}t$, $F^{G}t$-H, -E^{G}). For example, outwash deposits from Lussier River now stand as wide terraces in the Trench near Skookumchuck. Outwash from Elk River has formed gravel plains south and west of Elko and the broad flats of the Tobacco Plains (Plate 5.3).

These materials generally provide sites suitable for settlement and other forms of development, and agriculture, provided that surfaces are relatively stone-free. They are also potential sources of aggregate. Kettle depressions may be occupied by lakes or organic deposits. Kettle lakes provide potential recreation sites such as those which have been developed at Wasa and Baynes Lakes.

Extremely coarse and chaotic gravel or debris deposits resulting from glacier outburst floods (jökulhlaups) were identified at two locations. A large fan of debris (agF^{G}f-H, bgF^{G}ft-H) was constructed adjacent to the junction of Wigwam and Elk Rivers by a catastrophic flood which emerged from the meltwater channel now occupied by Silver Spring Lake, three kilometres east of Elko. Blocks of argillite* up to 6 m in diameter are scattered on the kettled surface of the fan, and smaller blocks can be traced southwestward on equivalent terraces to beyond Highway 93. Bouldery gravels of a major flood deposit constitute a kettled fluvioglacial area along Highway 93 between four and five kilometres north of Fort Steele. This flood probably descended the meltwater channel now occupied by upper Sauquim Creek and Sowerby Lake.

Meltwater channels result from erosion by streams draining from and alongside glaciers (Figure 2.2). They are typically steep-sided, flat-floored, and mostly underlain by outwash gravels. Their morphology varies from rocky gorges to wide shallow valleys amongst drift hills (Plates 5.3 and 5.4). Meltwater channels are indicated on terrain maps by use of on-site symbols for major and minor features. The modifying process symbol -E^{G} indicates that several meltwater channels (too small to map individually) occur within a terrain unit. In morainal* areas, meltwater channels may provide a supply of sand and gravel.

Many large meltwater channels are present along the sides of the Rocky Mountain Trench, particularly in the foothills of the Purcell Mountains (section 2.3.1).

Plate 5.4 View northward up meltwater channel near the confluence of Gold and Teepee Creeks. This is the largest of a series of parallel meltwater channels that formed here along the edge of a receding glacier.

5.3.5 ICE CONTACT DEPOSITS (F^Gh, F^Gr, F^Gt, F^Gu, -H, $-E^G$)

These materials consist primarily of sand and gravel in a variety of topographic forms, including hillocks, mounds, ridges and terraces. Terrain units are mapped objectively by using the most accurate descriptors for texture and topography (e.g. gF^Gh, sgF^Gur, sgF^Gth). Kettle depressions (-H) and meltwater channels ($-E^G$) are an integral part of this type of terrain.

Kames (gF^Gh) are conical mounds and hillocks of sand or gravel with local relief ranging from two or three metres up to several tens of metres (Plate 5.5). They formed where stream sediments were deposited in depressions on the glacier surface, and later melted out to form chaotically arranged hillocks and hollows.

Kame terraces (gF^Gtu-H) formed as outwash plains in depressions along the sides of a glacier between ice and adjacent mountainside. A steep, ice-contact scarp developed as ice receded and the outer edge of the terrace was left without lateral support. Collapse and slumping along this scarp, and melting of buried ice produced irregular and kettled terrace surfaces.

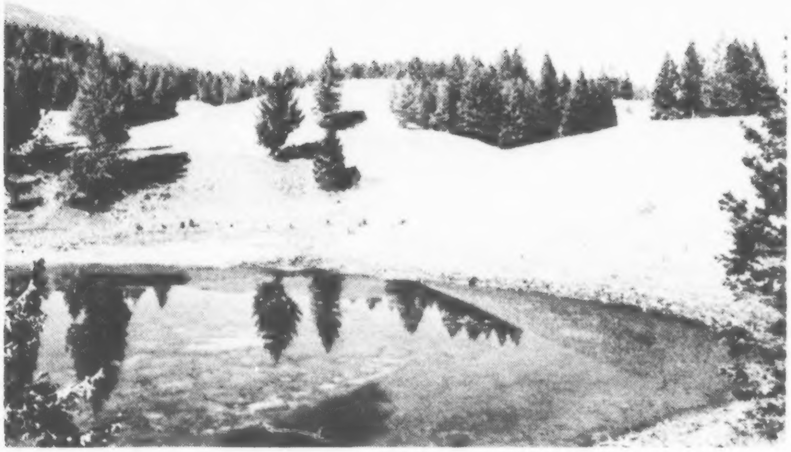

Plate 5.5 Kame and kettle topography (gF^{G}hr-H) on the western side of the Rocky Mountain Trench near Canal Flats.

Fluvioglacial sands and gravels occur as kames and kame terraces* at many locations within the Rocky Mountain Trench. Examples are located along the eastern side of Kootenay River north of Kootenay-Lussier confluence, and between Wasa Lake and Fort Steele. A large area of kame topography extends north-northeastward from Kimberley along Mather Creek. There are also large areas of kames and kame terraces along larger valleys within the mountains, such as those of Kootenay, White and Elk Rivers.

Eskers (gF^{G}r, and on-site symbol) are sinuous, steep-sided ridges of sand and gravel formed by the melting out of sediment-choked tunnels of sub-glacial streams. Their length varies from a few tens of metres to several kilometres, and their height ranges from a few metres to 20 or 30 metres.

In the East Kootenay region, eskers most commonly occur in association with other ice-contact fluvioglacial features where they are mapped as components of terrain units (e.g. sgF^{G}h$\underline{r}$u). Well defined eskers are rare: one good example is located on the west side of south Moyie Lake where it forms peninsulas that jut north and south from the fan of Etna Creek.

Chapter Six

Chapter Six

CHARACTERISTICS AND PROPERTIES OF LACUSTRINE MATERIALS AND ASSOCIATED LANDFORMS

6.1 DEFINITION AND MODE OF FORMATION

Lacustrine* and glaciolacustrine* sediments accumulated by settling from suspension in standing bodies of fresh water. They consist of sand, silt, and clay. Deltaic gravels are grouped with fluvial* deposits (gFl, gFf, gFt) for mapping purposes (Chapter Five). Glaciolacustrine deposits are normally distinguished by the presence of ice-related features such as kettles*, slump structures* resulting from ice-melting, and dropstones*. However, since the areal extent of some of these features is difficult to determine, and since they tend to occur sporadically within most bodies of lacustrine sediment, the two-fold division of lacustrine deposits was not generally adopted for mapping purposes. The term "lacustrine" as used from here on, is applied in an all-inclusive sense unless otherwise specified.

Lacustrine sediments were deposited in ice- and drift-dammed lakes at the end of Fraser Glaciation*. Most streams entering these lakes carried a high sediment load, since they were either draining directly from retreating glaciers or eroding and redepositing glacial sediments. Suspended stream load was distributed by lake currents over the lake floor, resulting in accumulation of layered fine sand, silt and clay. Seasonal or shorter term variations of river discharge resulted in influxes of alternately finer and coarser, or greater and lesser amounts of sediment. Gravel transported by streams as bedload was deposited as deltas.

Lacustrine sediments that predate the final phase of Fraser Glaciation occur in the Rocky Mountain Trench. They comprise most of the "Interdrift sediments", and "Young drift interstade" sediments indicated in Table 2.1, and outcrop beneath late-Fraser Glaciation till and fluvioglacial gravels in scarps along the Kootenay River and its major tributaries. They do not constitute mappable terrain units, but they may significantly affect land-surface properties, such as drainage, where they are thinly overlain by terrace gravels or other drift. A short description of these materials and their depositional history is given by Clague (1973).

6.2 CHARACTERISTICS , ENGINEERING PROPERTIES AND LANDUSE IMPLICATIONS

Lacustrine materials consist of moderately- to well-sorted silt, sand, and clay. Thinly interbedded or interlaminated fine sands and silts are most common, although massive silts and clays are not unusual. Bedding in thin lacustrine sediments generally runs roughly parallel to lake floor topography. In thicker sediments it tends to be roughly horizontal, although compaction and consolidation of material after deposition gave rise to local downwarping* and gentle dips*. Folds and contortions are present in places where sublacustrine slumping occurred, or where bedding was ruptured by escaping pore water during dewatering and consolidation (Plates 6.1 and 6.2).

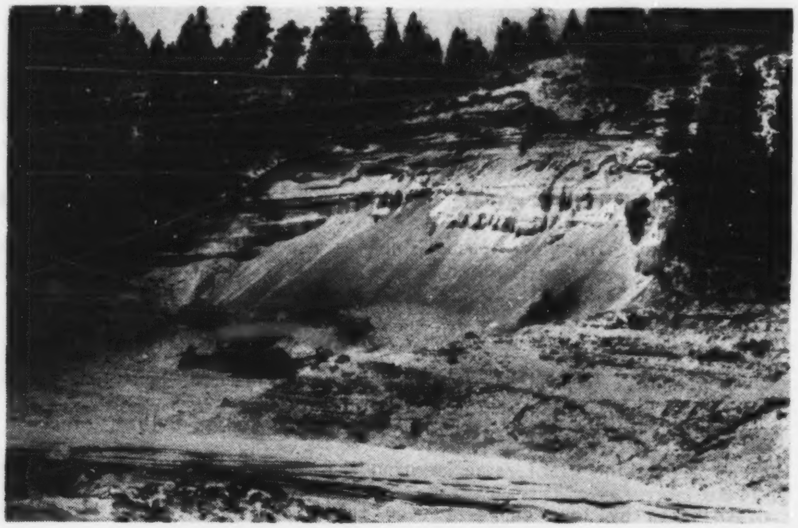

Plate 6.1 Horizontally bedded lacustrine sands exposed in bluffs on the eastern shore of Lake Koocanusa.

Ripple marks, cross-bedding, and scour and fill structures also occur in lacustrine sands. Load structures are common along silt-sand or fine sand-coarse sand contacts. Prominent blocky jointing develops in exposed vertical faces of silt or clay due to dessication and shrinking. From a distance this may mask most other structural features in the sediments. Ice-rafted stones, pods or lenses of gravel, and diamicton beds are found within glaciolacustrine sediments.

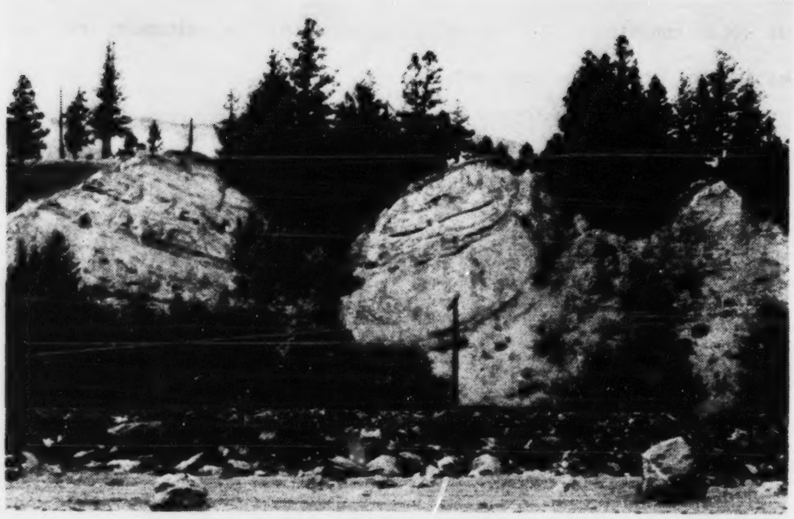

Plate 6.2 Western shore of Columbia Lake: downwarped glaciolacustrine silts and sands underlie a small kettle depression.

Lacustrine sediments are porous, but pore spaces in silt and especially in clays are so small, that even thin layers of these materials are effectively impermeable. Water movement may occur within sand layers in generally fine textured sediments, and this can lead to seepage and surface sloughing on steep slopes. Cut-banks that intersect such seepage zones may be perpetually unstable. Deep seated slope failure - particularly rotational slump - is common along scarp slopes in lacustrine silts and clays. It is usually caused by development of high pore pressures and resulting loss of cohesion of silt in zones of impeded groundwater flow. Natural slumps are common along lakeshore bluffs, river banks, and gullies (Plate 6.3). Slumping may also be caused artificially by addition of water from irrigation or other sources to terrace surfaces above and behind a silt scarp, or by undercutting or loading of the slope. In general, excavation and construction should not be carried out on steep slopes in lacustrine materials. Construction should also be avoided in a zone or belt along the terrace edge above the scarp, particularly if this would involve addition of water to the ground (irrigation, septic tanks, storm sewers).

Late-glacial lacustrine sediments are poorly consolidated and have low bulk density* (1.3-1.6 gm/cm^3) and low bearing strength*. Lacustrine sediments that were overridden by ice during the last glaciation are generally more highly consolidated (preconsolidated), and have higher bulk density (up to 1.8) and higher bearing strength, although these properties may vary greatly over short distances due to local conditions. Silts and clays are cohesive, although they break readily into blocks along dessication cracks and sand beds.

Plate 6.3 Northwestern Columbia Lake near Dutch Creek: slump-blocks of lacustrine silt in lakeshore bluffs.

Lacustrine silts and clays in particular, together with clayey till*, are the most plastic of all East Kootenay surficial materials. However, as can be seen from the figure in Appendix C.2, these materials are relatively non-plastic and non-compressible when considered within the total range of material ("soil" in the engineering sense) characteristics. Additional information regarding the properties of fine textured lacustrine materials and associated hazards in the Rocky Mountain Trench between Canal Flats and Edgewater is provided in a report by D.R. Haughton (1978) of the Geotechnical and Materials Branch, B.C., Ministry of Transportation and Highways.

Lacustrine silts and clays are affected by piping*. This process results in somewhat similar effects to that of solution in limestone, (it is sometimes referred to as "pseudokarst"), but in this case, tunnels and underground chimneys are formed due to the physical grain by grain removal of mineral particles. Groundwater flow is presumed to be responsible for this underground erosion. Surface collapse over underground cavities results in the formation of small, steep-sided depressions on the surface of lacustrine terraces. Presence of these features is the best evidence of present or former piping activity. Where piping is extensively developed, these depressions are commonly strung out in rows, like beads on a thread, marking the position of major pipes.

This process and its effects have been studied by staff of the Geotechnical and Materials Branch in South Thompson Valley near Kamloops (Evans and Buchanan, 1977), and in Okanagan Valley near Penticton (Nyland and Miller, no date). Piping is present in lacustrine silts that surround Columbia and Windermere Lakes, although it is not so strongly developed as in the two localities mentioned above. The presence and extent of piping should be investigated at all sites on lacustrine materials that are earmarked for potential development, since collapse due to piping is a potential hazard to people and property, and piping may be accelerated by additions to groundwater from human activities.

Lacustrine sediments are also vulnerable to gully and surface erosion by running water, and deflation (Plate 6.4). Extensive dendritic* systems of deep gullies have developed during postglacial time in lacustrine silt terraces, for example along the eastern side of the Trench between Fairmont and Windermere village. These processes may occur at the present time where surface vegetation cover is thin or absent.

Plate 6.4 Oblique aerial view of western side of Windermere Lake and MacCarthy Lakes (top centre). Terrain between road and lakeshore consists of lacustrine silts modified by gullying and piping (\$Ltu-VP). Irregular ridged topography around MacCarthy Lakes is underlain by ice-contact fluvioglacial gravels (sgF^{G}rht). Province of British Columbia, BC 891:113.

Lacustrine silt that has been reworked either naturally, as for example in the case of silt fans at the foot of gullies, or artificially, as in the case of silt used as fill for road embankments, is extremely susceptible to the processes of piping and gullying mentioned above. Such areas and utilizations should be strictly avoided.

In general, the physical properties of lacustrine sediments, particularly silts and clays, render them subject to various forms of instability and erosion. Detailed on-site investigations of geology, groundwater, hydrology, and engineering properties of materials will be necessary in any area where development is anticipated.

6.3 TERRAIN UNITS

The typical arrangement of lacustrine sediments and landforms within the present-day landscape is indicated in Figure 6.1.

6.3.1 LACUSTRINE TERRACES AND SCARPS (Lt, Ls, -P, -V, -F)

Late-glacial lacustrine deposits most commonly occur as terraces. They formed either due to dissection of old lake floors by post-glacial fluvial erosion, or due to lacustrine sediments being deposited, like a kame terrace*, in a depression between ice and valleyside. Lacustrine terraces in White River valley originated in the former manner, whereas those in Windermere Lake area probably formed by the latter process.

Terrace surfaces tend to be slightly irregular or gently undulating (Ltu) and may slope gently (0-4°) towards the centre of the valley. They are bounded by scarps (Ls or on-site symbol) 5 to 75 m high which, where they are most prominent, consist of an upper near-vertical face controlled by perpendicular dessication joints, and a lower, gentler foot-slope of silty colluvium. Falls of silt blocks - akin to rockfalls - may occur along steeper scarps in addition to the types of slope failure mentioned earlier (section 6.2) (Ls-F). Extensive gully systems have formed on many silt terraces (Lt-V), and piping depressions, if present, may be concentrated near the terrace scarp or extend in rows headwards from major gullies (Lt-P). Terrace surfaces may be mantled by eolian silt or sand $\frac{\text{sEvb}}{\text{Lt}}$ (section 8.1). This is usually thickest just above and behind terrace scarps and may constitute dunes.

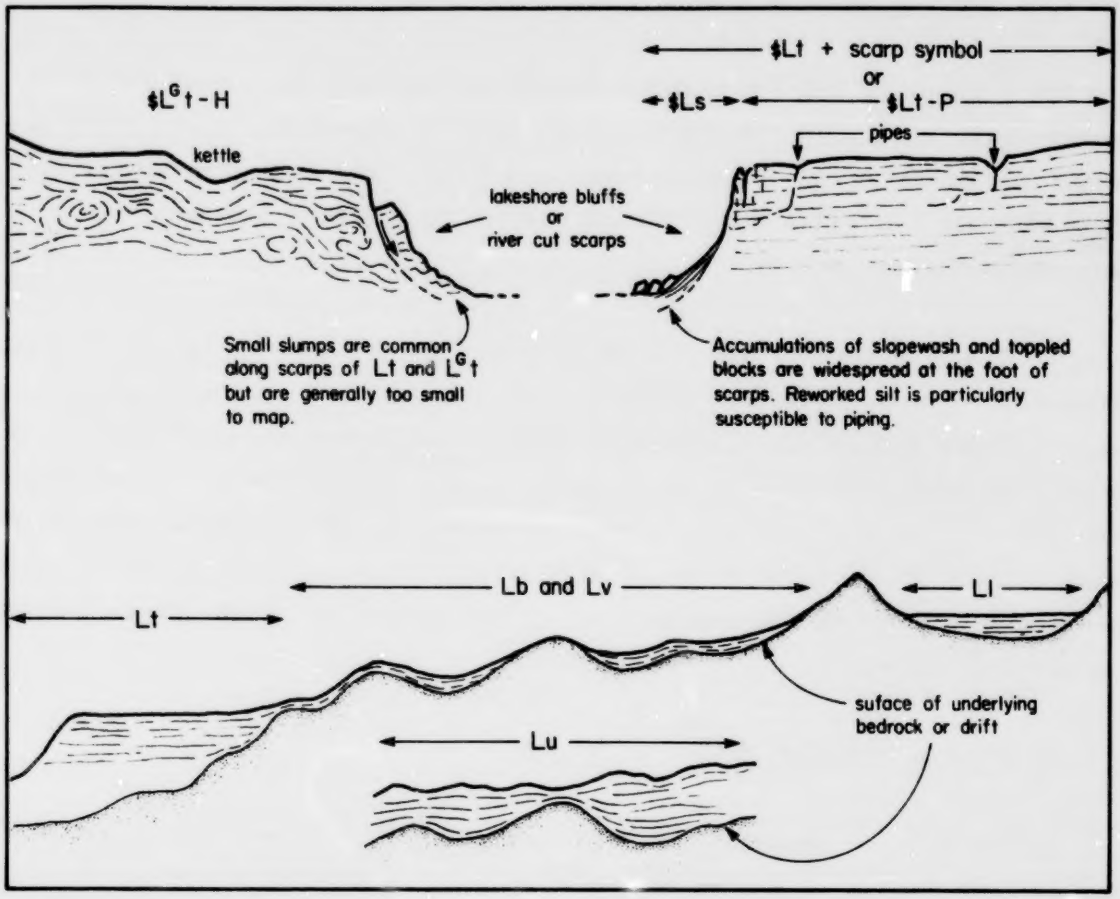
\$Lt + scarp symbol
or
$\$L^{G}t$ - H
\$Ls
\$Lt - P
pipes
kettle
lakeshore bluffs
or
river cut scarps
Small slumps are common along scarps of Lt and $L^{G}t$ but are generally too small to map.
Accumulations of slopewash and toppled blocks are widespread at the foot of scarps. Reworked silt is particularly susceptible to piping.
Lb and Lv
Ll
Lt
suface of underlying bedrock or drift
Lu

Figure 6.1 Cross-sections to ilustrate terrain units on lacustrine materials.

6.3.2 LACUSTRINE PLAINS (Ll, Lu)

These terrain units represent original, unmodified constructional surfaces on lacustrine sediments. They include areas of late-glacial sedimentation and also small lake basins infilled with postglacial sediments. Terrain of the latter type tends to be poorly drained with high water-table, and may undergo seasonal inundation. Organic sediments (section 8.3) may be interlayered or superimposed upon lacustrine sediments in these areas.

6.3.3 MANTLES OF LACUSTRINE MATERIAL (Lv, Lb)

Thin lacustrine sediments tend to reflect original lake floor topography, although they will be slightly thicker in depressions and slightly thinner over knolls (Figure 6.1). Higher eminences may project as "islands". Till islands surrounded by silt are mapped as composite terrain units ($\frac{\$\mathrm{Lvb}}{\mathrm{Mm}}$/Mm) in Elk River valley south of Elkford. Sediments tend to be of uniform thickness only where they overlie level surfaces.

This type of terrain is mapped as blanket (Lb) or veneer (Lv) depending upon the observed thickness of sediments. However, the accuracy of thickness estimates will depend upon the number of easily observable exposures such as roadcuts, so the terrain unit symbol b or v should be considered only a rough guide. Many units may contain inliers (islands) of other material. In particular, till inliers are hard to distinguish on air photos and may have been overlooked unless emphasized by a change in vegetation or landuse patterns. Conversely, lacustrine veneers and thin blankets cannot be recognized from airphoto interpretation alone, and they may have been omitted from the terrain map in inaccessible areas.

6.3.4 GLACIOLACUSTRINE SEDIMENTS (Lhu, L^{G}hu, -H)

The topography of ice-contact lacustrine (glaciolacustrine) sediments may be extremely irregular as a result of collapse and settling as buried ice blocks melted or retaining ice walls receded. Sediments of this type are, in many places, intermixed with ice-contact fluvioglacial* gravels and till.

6.3.5 LACUSTRINE SEDIMENTS NOT SHOWN ON TERRAIN MAPS

Lacustrine sediments are more extensive in many East Kootenay valleys than can be indicated on terrain maps. They occur as pockets too small to map and they underlie younger materials. These statements apply to other surficial materials too, but the distribution of lacustrine silts and clays is particularly important in view of their potential instability and erodibility.

In narrow mountain valleys, lacustrine silts and clays may have been eroded, terraced, and capped by fluvial gravels or colluvium during postglacial time. They may be exposed in high, steep stream banks, in which case their extent is hard to determine, or they may be totally obscured. If recognized, and if map-space permits, the presence of lacustrine sediments may be indicated by use of stratigraphic or composite symbols:

Examples: $\frac{\mathrm{gFt}}{\mathrm{\$L}}$ $\frac{\mathrm{rCf}}{\frac{\mathrm{gFt}}{\mathrm{\$L}}}$ Ca/gFl//$Ls

However, it is likely that unidentified or unmapped lacustrine sediments are present in many valleys. Even in broader valleys such as the Rocky Mountain Trench, this material is commonly overlain by alluvial fans*, outwash* gravels, or thick eolian* sediments.

Subsurface lacustrine deposits occur, or are more extensive than shown on the terrain maps, in the following areas:

- Kootenay River valley between Canal Flats and Kootenay - White River confluence
- Bull River valley north of Van Creek
- Elk River valley and lower parts of tributary valleys between Sparwood and Morrissey
- Michel Creek to Crowsnest Pass and tributaries
- Flathead valley south of Cabin Creek
- Wigwam River valley upstream from Fenster Creek
- valleys of Teepee, Bloom, Caven and Gold Creeks in the Purcell Mountains

Chapter Seven

Chapter Seven

CHARACTERISTICS AND PROPERTIES OF COLLUVIAL MATERIALS AND ASSOCIATED LANDFORMS

7.1 DEFINITION

Colluvial* deposits result from downslope movement of material due to gravity (mass movement). No agent of transportation is involved, although water, snow, or ice may constitute part of the moving mass. A variety of gravity-induced processes occur that result in formation of distinctive landforms and materials. A classification of those that occur commonly in the East Kootenay region is shown in Table 7.1. Various types of colluvial deposits are described individually below. Those processes which are significant because of their potentially hazardous nature are discussed further in Chapter Nine.

TABLE 7.1:

MASS MOVEMENT PROCESSES AND TYPES OF COLLUVIAL DEPOSITS

Process and Rate of Movement	Material Involved	Moisture Content	Resulting Landforms, Material and Terrain Unit Symbols[1]
Rockslide (Landslide) :rapid fall, slide, or dry flow	large mass of disintegrating bedrock	minor	slide deposits slide debris (r)aChr(mu)
Rockfall :rapid	individual blocks of bedrock	minor	talus slopes (a)rCa talus cones (a)rCf (gradient >30°)
Avalanche :rapid	individual bedrock blocks (minor constituent)	major (snow)	avalanche cones (a)rCf-A other avalanche slopes (a)rCavb-A avalanche tracks on other materials -A
Debris flow:moderate to rapid	silt and/or clay surrounding coarser particles	major	alluvial (colluvial) fans (g)dCf (gradient <20°)
Creep :slow	weathered bedrock or Quaternary deposits	minor to moderate	mantle of colluvium Cvb

[1] Letters in parenthesis indicate texture or surface expression terms which may possibly be present. Only one of the surface expression terms indicated in each symbol may be present. Texture may be omitted.

7.2 COLLUVIAL MANTLES (Cv, Cb)

Slow creep of surface material occurs down all slopes on unconsolidated deposits. It represents the cumulative effect of small downhill movements that occur each time the slope material is disturbed by processes such as frost heave, vegetation growth and decay, the passage of animals, or simply wetting and drying. Movement of this type is generally termed "soil creep", with "soil" used in the broadest sense to include all loose surface materials. Slopewash deposits* also are normally considered to be part of the colluvial mantle. Over the course of time a layer of dislocated, slowly moving material is formed on each hillside and surface irregularities are smoothed over.

Colluvium derived from and overlying unconsolidated Quaternary* deposits may be hard to distinguish from its parent material, although it is generally relatively loose and slightly stratified parallel to the ground surface. Since it normally does not differ in any unpredictable manner from material which it overlies, and since it may be expected to occur on all slopes (along with soil and weathered material), it is not specifically indicated on terrain maps. On many mountainsides however, colluvium consists of bedrock fragments derived from rock outcrops by frost shattering and other weathering* processes. These move downslope by creep processes that are augmented by sliding, small debris flows, snow creep, and similar effects. This colluvium (Cv, Cb, rCv, rCb) may overlie and mask bedrock, or it may have transgressed downslope over till*, or less commonly, other drift* materials (Plate 7.1). Figure 7.1 illustrates the relationship of rock outcrops, colluvial veneer and blanket, and till on a typical mountainside. Colluvial mantles of this latter type are indicated on terrain maps.

The texture of colluvium in Cv and Cb terrain units is largely controlled by characteristics of bedrock from which it was derived, such as spacing of joints and bedding planes, rock texture (particle size in sedimentary rocks, crystal size in igneous* and metamorphic* rocks) and the resistance of rock fragments to shattering upon impact and weathering. In general, thinly bedded and densely jointed rocks, such as some limestones and argillites*, produce rubbly talus* material. Massive limestones* and quartzites* break down to coarse, blocky debris. Shales*, friable sandstones* and other readily weathered rocks of the Fernie Basin give rise to fine textured, dark-coloured and relatively stone-free colluvium that is susceptible to surface erosion and slope failure ($rCvb, srCvb). Colluvium derived from phyllites* and siltstones* in the northern part of the East Kootenay region, has similar characteristics. A more detailed classification of colluvial mantles based on texture and associated bedrock types is presented in the East Kootenay soils bulletin and maps.

Plate 7.1 Mountainside east of Citadel Pass is mantled by colluvium (rCv) derived from underlying bedrock by frost shattering.

Pore spaces between rock fragments in rubbly or blocky colluvium are filled or partially filled with finer material derived by in situ weathering. The material as a whole is loose, non-compact, and highly porous* and permeable*.

The boundaries of Cv and Cb terrain units, material thickness, and the presence of underlying till or bedrock cannot be reliably determined by aerial photograph interpretation. Boundaries are commonly interdigitate or gradational (Figure 7.1) and observations of road cuts or natural exposures are necessary in order to distinguish blankets from veneers with any degree of certainty. In many areas, particularly on relatively soft rocks such as Fernie shale, till and colluvium are hard to separate. Consequently users of terrain maps should bear in mind the following:

1. Colluvium may overlie till in many Cv and Cb terrain units, particularly in relatively low valleyside positions.
2. Colluvium (unmapped) may overlie till in Mv and Mb terrain units, especially where rock outcrops occur at the top of a slope.

3. On forested hillsides without ground (road) access, the distinction of Cv from Cb and boundary line positions may be unreliable.

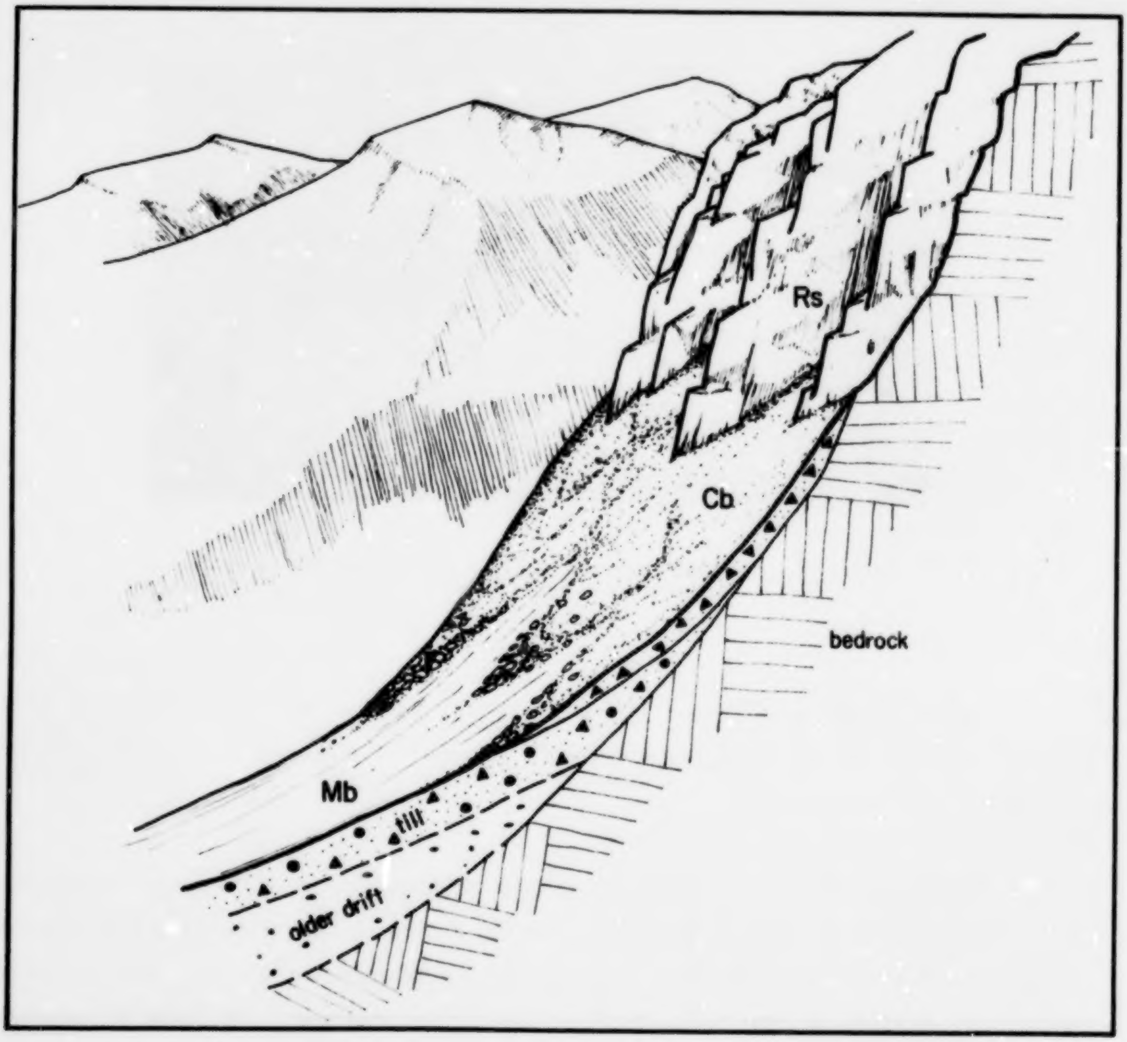
Rs
Cb
bedrock
Mb
till
older drift

Figure 7.1 Sketch to show typical relationship of till and colluvium on valleyside. This arrangement commonly occurs within composite terrain units such as Cb/Mb.

7.3 TALUS SLOPES (Ca, Cf)

These are accumulations of rockfall debris that occur at the base of cliffs, (see also section 9.2.2). Talus cones (raCf) form beneath gullies and couloirs that funnel falling rocks to a particular point at the base of a cliff. Talus slopes described as aprons (raCa) result from a more even distribution of debris, and are commonly coalescing cones. Talus landforms are distinctive and present no problems for mapping.

Talus slope profiles are straight with gradients close to 35°, which is the angle of repose* for granular materials. Slopes that presently receive much rockfall may be slightly steeper and susceptible to failure. Surface material will readily slide downslope when disturbed. Slopes modified by running water or avalanches (section 7.4) are gentler than rockfall talus slopes and their profiles are concave (Plate 7.2).

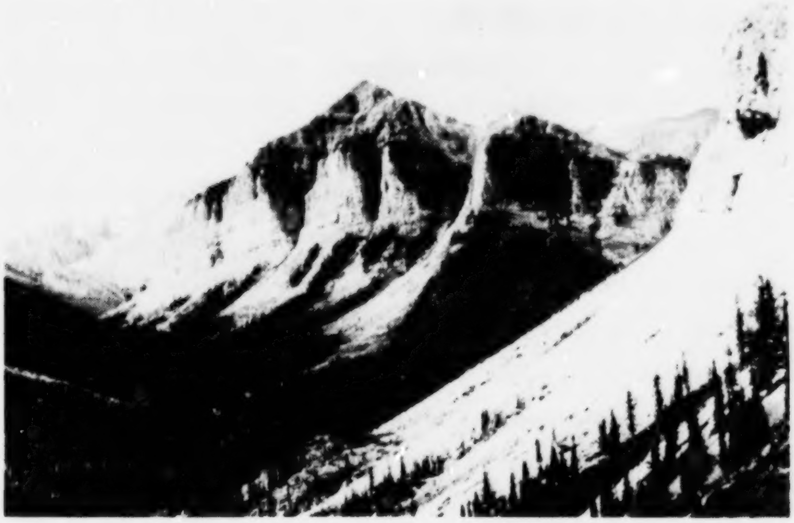

Plate 7.2 View up tributary of Cadorna Creek near Mt. Abruzzi in the Front Ranges of the Rocky Mountains. Straight profile of rockfall talus slope (rCa) in foreground contrasts with concave profiles of avalanche slopes (rCa-A) in middle distance.

The surface of talus slopes consists of rocky debris that becomes coarser downslope. The largest blocks are scattered near the base of the slope. Other characteristics and properties of talus are similar to those of material in Cv and Cb terrain units. Due to their steepness, instability and rockfall hazard, these areas are not suitable for roads or any other form of landuse. Some talus material may be useful for fill or aggregate.

7.4 AVALANCHES: LANDFORMS AND MATERIALS (Ca-A, Cf-A, Cv-A, Cb-A, -A, -AV)

Avalanches consist chiefly of snow but carry sufficient rock debris that distinctive avalanche deposits may accumulate over long periods of time. The hazards posed by avalanches are discussed in section 9.5 of this report.

Avalanche cones (Cf-A; coalescing cones Ca-A) accumulate at the foot of chutes and gullies (-AV) which channelize avalanching snow. They are distinguished from talus cones by their concave profiles, lower gradients (25-30° near apex), and avalanche tracks. The latter are defined by linear zones of vegetation in various stages of growth which radiate out from the cone apex along old avalanche scars. On many avalanche cones, a gully descends from the cone apex and contains a long-lasting snowbank or stream. Avalanche cones commonly receive material from rockfalls also: a complete graduation exists from talus cones (and slopes) to avalanche cones (and slopes).

Debris on avalanche cones is non-sorted and shows no downslope size gradation. Freshly deposited material may be extremely loose and unstable with blocks becoming precariously perched as they emerge from melting snow. Much woody material is commonly incorporated into avalanche deposits. Material within cones consists of angular fragments of various sizes with interstices partially filled with fine rubble, sand and silt. It is loosely packed, non-cohesive, and highly porous and permeable. Toes of avalanche cones (and avalanche slopes in general) are commonly seepage sites since snow meltwater from higher slopes percolates through the cones and emerges at their base.

Other avalanche slopes (Cv-A, Cb-A) are mapped where a mantle of avalanche debris overlies bedrock or valleyside drift. This has the same physical characteristics as material in avalanche cones, although its total thickness may be only one or two metres.

Avalanche tracks (-A) and gullies (-AV) may cross areas where no deposition of avalanche debris has occurred. These may be mountainsides too steep to retain any loose material (e.g. Rs-A), or slopes where avalanche effects are erosional rather than depositional (e.g. Mb-AV).

Identification and mapping of avalanche features is accurate where modern avalanche tracks exist, since these features can be clearly recognized on air photos. However, the differentiation of avalanche deposits of various thicknesses (Cv vs. Cb), and the separation of avalanche slopes with no avalanche deposits (e.g. Mb-A) from slopes with a thin mantle of debris (e.g. $\frac{\text{Cv}}{\text{Mb}}$ - A), is less reliably interpreted and requires ground checking for confirmation.

7.5 ROCKSLIDES: LANDFORMS AND MATERIALS (Chr)

Rockslides involve detachment and rapid downslope movement of large disintegrating masses of bedrock with a volume of several tens of thousands or millions of cubic metres (see also section 9.2.1). Slide deposits have an irregular, hummocky surface on which large blocks may be exposed, and steep, abrupt margins (aChr). Their overall plan is lobate or tongue shaped, and this form may be emphasized by ridges and furrows reflecting the original pattern of movement. There may be evidence of ponded drainage up-valley, and rivers crossing slide debris typically occupy narrow irregular channels with rapids. A steep, crescentic scarp (landslide scar on-site symbol) generally marks the original site of failure. These characteristics are sufficiently distinctive that rockslide deposits are recognized without difficulty by an experienced aerial photograph interpreter.

Rockslide debris consists of chaotically arranged fragments of bedrock which range from rubble to blocks as big as houses. Size of fragments and interstitial material is controlled by bedrock characteristics (section 7.2) and the degree to which the original rock mass disintegrated during movement. Slide debris is highly permeable and may contain large voids.

Large blocks in slide debris will require drilling and blasting for excavation. The debris may be utilized for rip-rap, building stone, or even as an aggregate source (Cruden, 1976).

Rockslides are scattered throughout that part of the study area that lies within the Rocky Mountains. They are most common in areas of dipping limestones, dolomites* and quartzites, since most failures occur by slippage along bedding planes. Many small slides are included in "Rs" and "Ca" terrain units.

7.6 DEBRIS FLOWS: LANDFORMS AND MATERIALS (Cf, dCf)

Debris flows occur when saturated, fine textured material flows downslope as a viscous liquid (see also section 9.3). Fine material (silt and clay) alone may be affected, or, as is most commonly the case, coarser debris may be carried along in a mud matrix. "Mudflows" are sometimes differentiated from "debris flows" on this basis. Flows are initiated when unconsolidated materials of appropriate texture on steep slopes become saturated due to heavy rainfall. They may be triggered by small slides or slumps. Till, colluvium, and lacustrine* silts are susceptible. This process, along with erosion by running water, leads to development of gullies on till covered slopes (Mb-V) and formation of small debris flow fans at their foot (Plate 7.3).

Plate 7.3 Small gullies formed by debris flows down colluvial slope near Bleasdell Creek, upper Elk River area.

Debris flow deposits comprise small and steep alluvial (colluvial) fans* (dCf, Cf) (see also alluvial fans, section 5.3.3) with surface gradients of up to about 20°. Material is bedded and commonly interlayered with thin fluvial* gravel and sand. Each debris flow consists of massive, till-like diamicton*; coarse fragments of various shapes and sizes are set in a matrix of sand, silt, and clay, which provides overall cohesion to the material. Consolidation is less than that of till, but greater than that of fluvial or eolian* materials.

Colluvial fans that consist of fluvial and debris flow material may be used as a source of fill, and may possibly supply aggregate material if "pure" fluvial gravels are unavailable. Fans of this type generally provide suitable foundation conditions for roads and other construction, but a potential debris flow hazard may exist, especially near a fan apex. Detailed site investigations should be performed.

7.7 COLLUVIAL LANDFORMS AND DEPOSITS IN ALPINE AREAS (-S, -C)

Several distinctive forms of colluvium have been mapped in alpine areas.

Blockfields (on-site symbol) are extensive areas of blocky debris. They form on level or gently sloping mountaintops or ridgecrests due to frost shattering of bedrock.

Rock glaciers (on-site symbol) are glacier-like tongues of blocks and rubble which occupy cirques* or other cliff-foot sites. Examples are located in north-facing cirques near Mount Assiniboine. They contain a core of glacier ice or interstitial ice. Active rock glaciers undergo slow movement; they are ridged and furrowed and have steep, lobate, frontal slopes.

Solifluction (-S) is slow downslope movement of saturated overburden across a frozen or otherwise impermeable* substrate. The material affected may thus be designated as colluvium. It generally consists of either the weathered upper portion of till, (Mv-S, Mb-S) or weathered bedrock (Cv-S, Cb-S), or a combination of both materials. Note that terrain map symbols indicate parent material and modifying process. Solifluction is occurring to a greater or lesser extent on all slopes (other than bedrock) in alpine areas, but is mapped only where solifluction features such as lobes, benches or stone stripes are particularly well developed.

Cryoturbation (-C) refers to the processes of frost heaving and churning that result from seasonal freezing and thawing of surface materials in areas of severe winter climate. It is most active on vegetation free surfaces and exposed slopes that are not insulated by a thick snow pack during winter. Patterned ground (stone circles, polygons and stripes) and distorted and contorted organic layers and other soil horizons result from cryoturbation. The process is indicated on terrain maps only where it was observed in the field, although like solifluction, it is presently occurring to a greater or lesser extent within most morainal and colluvial units above tree line.

Chapter Eight

Chapter Eight

OTHER TYPES OF MATERIALS AND ASSOCIATED LANDFORMS

8.1 EOLIAN DEPOSITS AND LANDFORMS

8.1.1 DEFINITION AND MODE OF FORMATION

Eolian* deposits result from wind action. Loose sand and silt grains on bare ground are set in motion by strong winds. Larger particles travel along within a few centimeters of ground level by rolling or bouncing, whereas finer particles are swept aloft and carried in suspension by turbulent air currents. The former process is responsible for the construction of dunes, whilst the latter gives rise to thin but widespread surface mantles of fine material.

In the East Kootenay region, eolian processes were probably most effective during deglaciation before the establishment of general vegetation cover. Sand and silt particles were swept up from outwash plains and other surfaces underlain by non-cohesive materials and deposited on adjacent sites. Since then, deflation (wind erosion) has continued on active floodplains* and along river bank scarps where unconsolidated sediments are exposed. It may also have been effective in sparsely vegetated areas in the drier, southern part of the Rocky Mountain Trench.

8.1.2 CHARACTERISTICS, ENGINEERING PROPERTIES AND LANDUSE IMPLICATIONS

Eolian sediments consist of moderately- to well-sorted silts and fine to medium textured sands. Fine textured eolian deposits resemble loess* and generally consist of massive* silty fine sand or sandy silt. They are non-consolidated yet they are cohesive (due chiefly to weak cementation by calcium carbonate) and tend to form vertical faces in shallow excavations. They may settle and compact when loaded, and are subject to hydrocompaction*. However, mantles of eolian material are generally so thin (less than one metre) that foundations are based in underlying material.

Dunes typically consist of well-sorted fine to medium textured sand. This may be massive or thinly bedded with cross-bedding* and ripplemark* structures. Dune sands are loose, non-cohesive, and poorly consolidated.

Eolian deposits in general are highly porous* and permeable* and give rise to well-drained, stone-free soils. When ploughed or otherwise disturbed however, bare ground is susceptible to deflation and loss of topsoil.

8.1.3 TERRAIN UNITS (Eu, Em, Ev, Eb, -D)

Dunes form areas of undulating or rolling terrain (sEu, sEm, dune on-site symbol) with local relief of 2 to 4 m. Examples can be found south of the mouth of Gold Creek (Plate 8.1) and along Highway 99 just north of Ta Ta Creek. Dunes with classic ridged or crescentic forms were not found in the study area.

Plate 8.1 Roadcuts through stabilized sand dunes (on-site symbol) on terrace near the mouth of Gold Creek, southern Rocky Mountain Trench.

A layer of fine-textured eolian sediments (sEv, sEb) covers much of the lowlands within the Rocky Mountain Trench and the Flathead and other major valleys. It is thickest (1 to 2 m) on terraces and fans close to floodplains* and bluffs that provide a supply of fine material. Eolian veneers and blankets are shown on terrain maps where they constitute a well defined surface layer of fine material that is separated from underlying gravels or other deposits by a clear basal contact. In many other terrain units however, particularly on morainal* areas in the Trench, a thin surface layer of fines grades downward into underlying stoney material. This probably results from a combination of pedogenic* and eolian processes and is not generally shown on terrain maps.

Dunes on terraces and fans can be recognized on air photos with a fair degree of reliability unless masked by forest cover. In hilly areas and under dense vegetation, dunes generally can only be identified by ground checking. Similarly, the presence and extent of eolian veneers and blankets can only be confirmed by ground work. Consequently, all these features may be more extensive than shown on terrain maps.

8.2 BEDROCK (R, Rs, -G, -N, -K)

Bedrock (R) is shown on terrain maps where it is exposed at the ground surface or covered by less than 10 cm of weathered* rock or other material. Rock cliffs and bluffs (Rs) are the most common bedrock terrain unit. Areas of gently dipping or horizontal limestones*, quartzites*, and other resistant rocks characteristically show step-like topography where cliff bands alternate with talus* slopes (Rs.rCa). In terrain units designated by R alone, with no surface expression indicated, topography conforms to that shown by contour lines.

Land surface properties in these areas and the nature of any associated colluvium* depend upon local rock types. These have been mentioned briefly earlier in this report (Chapter Two and Table 2.2). Readers are referred to publications of the Geological Survey of Canada and the British Columbia Ministry of Energy, Mines and Petroleum Resources, which are listed at the end of this report, for geological maps and detailed descriptions.

Processes that commonly modify rocky areas include frost shattering* (-G), nivation* (-N) and avalanching (-A; section 7.4 and section 9.5). Frost shattering is a physical weathering process whereby bedrock or rock fragments are split and broken due to expansion of water upon freezing in joints and other fissures. Its effects, such as surface rubble and talus slopes, are ubiquitous in all rocky areas, particularly at high elevations. This process is indicated (Rs-G, R-G) only where it is judged to be particularly effective or significant. Materials and landforms described elsewhere in this report that result wholly or partially from the frost shattering process include colluvial mantles (section 7.2), talus (section 7.3), blockfields* (section 7.7), and rock glaciers* (section 7.7).

Nivation is a process of erosion that occurs locally beneath and around persistent snowbanks. It results from a combination of physical and chemical weathering, slopewash, and snowcreep, and is most effective in alpine areas near the summer snowline. Hollows within which the snowbanks lie are deepened and enlarged, and may develop into irregular benches or small cirque*-like forms (Plate 8.2). Nivation features are common on bedrock (R-N) and also in morainal or colluvial areas (e.g. Mb//Cv-N, Rs.Cvb-N).

Plate 8.2 Shallow depressions formed by nivation on northeast-facing side of ridge between Palliser River (lower right) and Fenwick Creek (Rs/rCa-NA). Note extent of avalanche paths.

Carbonate rocks (limestone, dolomite*) and gypsum* are affected by the chemical weathering and erosion process of solution. Narrow openings such as joints and bedding planes are enlarged by slow solution into groundwater. Ultimately, subterranean drainage systems develop with caverns and tunnels. Sinkholes*, closed depressions, blind valleys (no outlet), bare limestone pavements, and intricately fretted rock outcrops are the surface manifestations of this process. The term "karst"* denotes terrain with these distinctive features. The karst modifier (e.g. R-K) is applied to terrain units where solution features are visible on air photos (chiefly sinkholes), or where they were noted on the ground (chiefly cave entrances in cliffs). Good examples of many karst features may be seen in the central part of the Lizard Range.

Solution features are well developed on gypsum beds of the Devonian Burnais and Harrogate Formations in the Hughes Range. Sinkholes affecting both bedrock and overylying till $(\frac{\text{Mb}}{\text{R}} - \text{K})$ are common in the valley of Lussier Creek. They have been studied in some detail, along with associated features, by Wigley et al. (1973).

8.3 ORGANIC MATERIALS (Ol, Ov, Ob)

Organic deposits result from decay and accumulation of vegetative matter. They occur in and around depressions and old lake basins in rock or drift, and in areas of high water table such as backswamps or cut-off meanders* on floodplains and abandoned meltwater channels*. Organic materials may be interlayered with marl* or inorganic detritus.

For more information related to organic deposits and to organic soils in particular, readers are referred to the East Kootenay soils bulletin.

8.4 ANTHROPOGENIC MATERIALS (A, Ah, At)

Anthropogenic terrain units (A) are mapped where human activity has modified natural materials and landforms to the extent that their original characteristics have been drastically altered. In the East Kootenay region they include spoil heaps, tailings, and open pit mines (A, Ah, At, etc).

8.5 UNDIFFERENTIATED MATERIALS (Us)

The symbol "Us" is applied to scarp slopes which cut across a layered sequence of three or more different kinds of materials. The materials cannot be shown individually because of limited space on the terrain map. For example, "Us" terrain units along Elk River southwest of Elkford are scarps in which the following sequence of materials is exposed:

postglacial fluvial* gravels
till* containing lenses of sand and gravel
till
lacustrine* clay, silt and sand
colluvium (pre-Quaternary fans, partially consolidated)
silts and sands (pre-Quaternary, partially consolidated)
bedrock

Chapter Nine

Chapter Nine

GEOLOGICAL HAZARDS

9.1 INTRODUCTION

Certain geological processes are active at the present time. They range from imperceptible but universal effects, such as rock weathering* and soil creep*, to catastrophic but rare events that become historical landmarks, such as the 1903 landslide at Frank, Alberta, and the 1964 earthquake at Anchorage, Alaska. These are all natural processes and they operate according to physical and chemical laws in response to conditions on or near the earth's surface. Many different factors of geology, climate, and topography control the operation of each process, so that mechanisms are complex. Events that are controlled by seasonal weather changes, such as high river discharge resulting from snowmelt, and avalanches, can be foretold to some extent. The timing of other sporadically occurring phenomena, such as major rockfalls and debris flows, is virtually impossible to predict, although areas susceptible to these effects may be delimited.

Most geological processes are perceived as "natural hazards" when human activities occur within their zone of operation. Danger to life and property may be particularly great where low frequency but high magnitude events occur, allowing people to unwittingly occupy a site for decades prior to a disaster. It is thus essential that areas affected by potentially hazardous geological processes be identified as a preliminary step in any landuse planning process. These areas should preferably be avoided, especially for high intensity uses such as residential buildings. If this proves impossible, for example in the case of a routeway crossing avalanche tracks, detailed on-site studies must be carried out. These should determine, as precisely as possible, the extent of threatened areas, the probability or frequency of hazard occurrence, and appropriate protection or mitigation measures.

In addition to the natural processes described above, certain geological effects may be accelerated or even initiated by a particular landuse or other human activity. Soil erosion, for example, may be provoked by inappropriate agricultural practices, and rockslides may be triggered by undercutting potentially unstable slopes during mining or road construction.

Many present day geological processes are indicated on terrain maps by modifying process symbols and "active" process status descriptors. Accordingly, terrain maps can be used for a general regional survey of areas susceptible to certain hazards. However, these maps are not suitable for detailed analysis of geological hazards affecting particular sites or small areas. Also, places where man-induced or accelerated geological hazards may occur cannot be adequately identified by regional reconnaissance methods, although it may be generally assumed that most modern processes of mass wasting*, erosion, and runoff will be increased by land clearance and surface disturbance.

Geological processes that constitute natural hazards in the East Kootenay area are discussed below. Derivation of a hazard map from a terrain map is described in the last part of this chapter.

9.2 SLOPE PROCESSES: MASS MOVEMENT OF BEDROCK

9.2.1 ROCKSLIDES

These have been defined and associated deposits have been described earlier in this report (section 7.5). Major rockslides are rare catastrophic events. They are likely to occur in any mountainous region with steep valleyside slopes, but are relatively common in areas of dipping stratified rocks.

Some generalities regarding the causes of rockslides may be drawn from the work of D.M. Cruden (1976). He studied rockslides in the Front and Main Ranges of the Rocky Mountains in Alberta, but his conclusions apply also to adjacent areas of similar terrain within British Columbia. Slides most commonly occur in thickly bedded, massive rocks such as quartzites*, dolomites* and limestones*. Failure and slippage take place along bedding planes dipping valleywards at 30° to 40°. Undercut dip* slopes are most susceptible. Joint enlargement in limestone by solution may aid detachment of the slide mass. Slides also result from failure along complex geological discontinuities.

Rockslides may travel a considerable distance (up to several kilometres) from their source, dependent upon local topography. Debris may also overwhelm low hills on the valley floor or ascend an opposing slope to a height of several hundred metres. In addition, debris flows or floods may be generated by a slide if it encounters a lake or river, and these could affect areas far downvalley.

A knowledge of regional landslide characteristics together with detailed investigations of local geological structure, lithology and topography may enable slope stability to be evaluated and potential runout zones identified. This should be done as an early step in the planning process for locations that are to be intensively developed, such as townsites and campsites. For other developments, such as roads, areas of apparent instability should be avoided and artificial disturbance that could trigger failure, such as undercutting or loading of slopes, should be carefully assessed. It is not practicable however, to make a realistic appraisal of rockslide hazards on a regional scale. The terrain maps indicate unstable slopes (-F) only where features associated with presently occurring slope movement are visible, such as tension cracks and fresh slide scars. No general attempt has been made to identify sites that are threatened by rockslides.

9.2.2 ROCKFALLS

Rockfalls occur when rock fragments become detached from cliffs or steep slopes and fall, slide, roll, or bounce to lower elevations. The term is generally applied to falls involving a relatively small mass of material or even single fragments. Talus* slopes (section 7.3) form where rockfall material accumulates at the foot of cliffs.

Blocks of bedrock are loosened from cliffs and other bedrock exposures by physical and chemical weathering processes that act to enlarge joints, bedding planes, and other fractures. Frost shattering* (-G) is particularly important (see also section 8.2). Cracks are widened due to pressures exerted by ice crystal growth in a confined space. Blocks generally become detached when thaw occurs. Rockfalls are most common during spring, since it is the annual freeze-thaw cycle that is most effective, although they can occur at any time. Rock type also influences magnitude and frequency of rock falls: highly fissured hard rocks, such as thinly bedded limestones and argillites*, are most susceptible.

Rockfall represents a hazard to areas at the foot of steep rock slopes. Its activity may be roughly assessed by observing the numbers of fresh angular fragments that are present on the ground surface in such areas. Impact scars may be present on tree trunks, ground surface or any other natural or man-made structures where rockfall commonly occurs. Rockfall may pose a local hazard along highways or railroads beneath rock cuts or natural rock bluffs.

9.3 SLOPE PROCESSES: MASS MOVEMENT OF CHIEFLY UNCONSOLIDATED MATERIALS

A variety of types of slope failure affect fine textured unconsolidated materials such as lacustrine* silts and clays, and tills* with silt or clay matrix. They are classified according to the kind of movement and water content of the displaced mass. The chief types are described below.

Slumps involve displacement of a mass of material (unconsolidated or bedrock) that remains internally cohesive. Movement may occur along either a planar or a concave upward (rotational slump) surface. It may be rapid, slow, or pulsatory in response to varying moisture conditions. Rotational slumps occur in homogeneous, structureless materials, and may be initiated by undercutting of slopes due to natural or artificial processes.

Earthflows involve slow (imperceptible) flowage of moist masses of unconsolidated material. They develop a tongue-like or lobate form with a steep frontal slope and surface wrinkles and furrows that reflect the pattern of movement.

Debris flows and mudflows involve rapid flowage of saturated material. They have been described previously in this report (section 7.6).

These types of failure are generally caused by high moisture conditions which may devolve from groundwater or precipitation. Flowage or failure takes place when high pore pressures within the material cause loss of cohesion, either of the whole mass, or along a subsurface zone which then functions as a slide plane.

The following generalizations can be made regarding terrain units affected by these processes in the East Kootenay region:

1. Scarp slopes in fine textured lacustrine materials ($Ls, $Ls-F, scarps in $Lt units, landslide scar symbol on $L units, equivalent cL units) are prone to slumps and minor earthflows (Plate 6.3). These processes will be particularly active if groundwater table lies at shallow depth beneath the base of the slope (see also section 6.2). Falls of silt or clay blocks which become detached along vertical joints also occur on near vertical bluffs.
2. Scarps and artificial cuts in silt and clay tills ($Ms, cMs) are also common sites for slumps and minor earthflows controlled by moisture conditions.

3. Debris flows tend to occur on moist (heavy rainfall, snowmelt, impeded groundwater flow), steep slopes of till or colluvium (Mvb, Cbv). They are relatively common where colluvium is derived from shale, phyllite, sandstone, or other relatively soft, fine grained clastic rocks (e.g. $rCvb). Slopes where debris flows occur relatively frequently may be gullied (-V) and flanked by a piedmont of small debris flow fans. These may occupy too small an area to constitute a map unit, but are clearly defined on the ground.
4. Small, steep alluvial (colluvial*) fans* (dCf, some Cf) are sites of debris flow deposition (section 7.6). Flows may occur sporadically at intervals of decades or longer in response to abnormal rainstorms. The presence of mature vegetation is not a reliable indicator of inactivity, and intensive development should not take place near apexes of such fans. It is difficult to assess the likelihood of future catastrophic events.

9.4 SLOPE PROCESSES: EROSION

Removal of particles by flowing water may take place generally over a slope giving rise to sheet erosion and slopewash deposits at lower elevations, or it may be concentrated along shallow rills, which become enlarged to form gullies or ravines. The former situation is hard to identify unless severe, but gullies (-V) are generally visible on air photos, although small features may be masked by tree cover (Plate 9.1).

Plate 9.1 Gullied till (Mb-V) in basin of Bleasdell Creek, upper Elk River area. Stream erosion is occurring along some gullies; others appear to be stable.

The presence of gullies can be used as a rough indication of materials that are susceptible to erosion (and also debris flows, as mentioned above). Lacustrine silts and tills with fine textured matrix on steep slopes are commonly gullied (e.g. $Lt-V, $Mb-V). Gullies in lacustrine silts have been described earlier in this report (section 6.2). On till covered hillsides, gullies trend directly downslope. They are parallel or subparallel, and from one to ten metres deep. Bedrock may be exposed in the gullies. Although these gullies may not be actively enlarging at present, it is likely that indiscriminate removal of vegetation, or inadequate control of sidespill and drainage from road construction, could trigger further erosion or debris flows.

Gully development on the middle or lower part of a slope is controlled to a large extent by runoff (surface and subsurface) from the higher, non-gullied parts of the same slope. Therefore, precautions applied to the gullied area should also be applied to adjacent areas up slope.

9.5 SLOPE PROCESSES: AVALANCHES

Avalanches are rapid, downslope movements of snow, ice and incorporated debris (see also section 7.4). They are powerful, destructive forces that have been responsible for considerable loss of life and property damage. Studies carried out over the last few decades have led to development of methods for analysis of snow conditions, avalanche prediction, and avalanche control (cf. Perla and Martinelli, 1976). Accordingly, avalanche hazards can be minimized in highly vulnerable areas such as ski developments and along major highways, as has been done at Rogers Pass. However, reduction of avalanche hazard should still depend primarily upon identification and avoidance of avalanche prone areas.

The area affected by an avalanche - avalanche path - can be divided into three sections: starting zone, track, and runout zone. Most starting zones are bare, or contain only sparse timber, and are steeper than about 30°. They are sites that receive large amounts of snow, such as lee slopes, and gullies and bowls bounded upslope by cliffs. The avalanche track is the route followed downslope by a snow slide (Plate 9.2). It may be confined to a gully (-AV) or unconfined on an open mountainside (-A) (see also section 7.4). Avalanche tracks may cross gentle slopes or even level terrain. The runout zone is the lower part of an avalanche path where sliding snow comes to rest. It usually encompasses avalanche cones, if present, and other parts of the valley floor, but it may also extend up hill on the opposite valleyside.

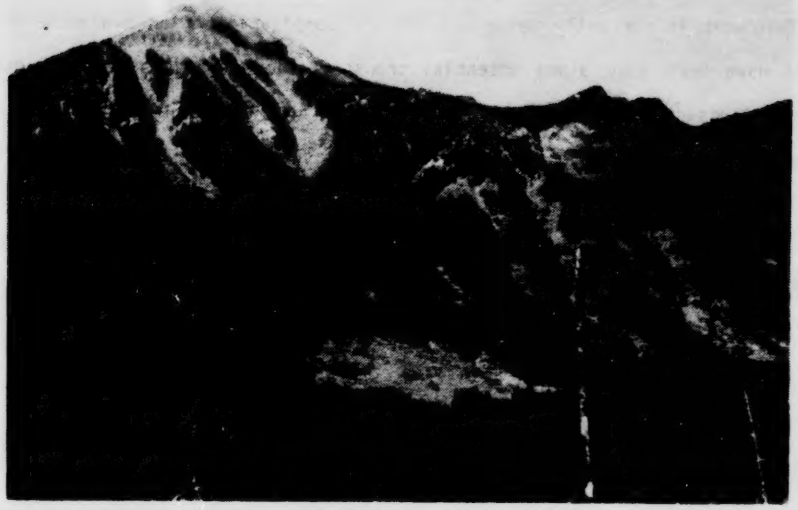

Plate 9.2 Avalanche paths on western side of Elk River valley near Crossing Creek. Note that starting zones are vegetation free, rocky areas, and note extent of runout zones on gentle slopes.

The terrain maps indicate terrain units that encompass avalanche tracks and runout zones that are sufficiently active to maintain a distinctive vegetation cover. However, although avalanches tend to follow the same paths year after year, certain unusual circumstances may cause unexpected deviations. For example, abnormal snow accumulation during unusual winter weather may give rise to larger, or wetter, or greater numbers of avalanches. Runout zones may be extended through forest into formerly protected areas, or completely new paths may be formed. Avalanche patterns may also be inadvertently modified by deforestation. Care should be taken to avoid removing vegetation from potential starting zones or buffer strips around runout zones where increased avalanche activity would threaten settlments or routeways. It is wise to assume that existing avalanche tracks and runout zones represent a very conservative indication of areas that are likely to be affected by avalanche activity.

Avalanche starting zones above timberline are not generally indicated on the terrain maps since specific studies are required for their identification. These should be carried out if ski developments or other intensive activities are planned for the alpine zone.

The Avalanche Task Force (1974) identified several areas near Fernie where avalanches affect Highway 3. This work is currently being updated and compilation of an avalanche atlas is underway. Other studies have been done along potential transportation corridors leading into Flathead River valley and around adjacent townsites such as Fernie and Sparwood. Information is available from the Avalanche Section of the Maintenance Services, British Columbia Ministry of Transportation and Highways.

9.6 RIVERS: FLOODS AND EROSION

Fluvial* processes are perceived as hazards where human activities take place on floodplains*. These areas should be considered as normal high-water parts of river channels. The timing and volume of floods can to some extent be predicted, and protective measures against both floods and erosion can be engineered. However, for long term safety and economic reasons, it is generally preferable to plan land utilization so that settlement, industry, and routeways avoid hazardous areas.

Hazards arising from fluvial processes include flooding (inundation), bank erosion and shifting of channels. The use of terrain unit symbols to designate areas that experience these conditions has been described earlier in this report (section 5.3.1 and section 5.3.3). In general all active fluvial areas (F^A, $-E^A$), and Fl units adjacent to channels should be considered as potential hazard zones. Alluvial fans with surface rather than incised channels (F^Af and Ff) also experience flash floods, shifting channels, and possibly debris flows. Bank erosion along single-strand channels should also be considered, although it is not indicated specifically on terrain maps. It tends to be localized around the outside (undercut bank) of meanders* and other bends along a river course.

Floodplains along small mountain creeks may not be shown on terrain maps due to space restrictions. However, it should be recognized that these creeks experience great variations in discharge and occasional catastrophic floods.

Detailed floodplain mapping (1:5000 or 1:2500) along major rivers is carried out by the Planning Section of the Water Investigations Branch of the British Columbia Ministry of Environment. These maps are intended to assist planning and regulation of new development on floodplains, and design of protective measures for already existing development where warranted by economic and human safety considerations. In the East Kootenay area, mapping is currently being done along Kootenay and Columbia Rivers in the Rocky Mountain Trench, along Elk River between Morrissey and Forsyth Creek, and along the valley followed by Highway 3 between Sparwood and Crowsnest Pass. These maps will show areas that would be inundated by a flood with a recurrence interval of 200 years, that is, the largest flood that can be expected to occur, on the average, once every 200 years.

Flood hazard mapping at 1:20 000 along watercourses near Fernie, Sparwood, Elkford and Forsyth Creeks was done as part of an urban suitability study carried out by the Resource Analysis Branch (Karanka, 1977). A historical summary of floods along Elk River is also included in that report.

9.7 WIND EROSION

Wind erosion, (deflation -D) may remove coarse silt and fine sand particles where loose material is exposed at the ground surface (see also section 8.1). This may occur naturally where vegetation is sparse, as in semiarid areas of the southern part of the Rocky Mountain Trench, or it may occur where bare ground is exposed by human activities such as agriculture or land clearing for construction. Areas of eolian deposits are generally susceptible to further wind erosion if protective vegetation is removed.

Hazards posed by wind erosion are relatively minor. Blowing sand and silt may reduce visibility. Long term deflation results in loss of topsoil.

9.8 PIPING

Piping* may cause local collapse and settling in fine textured lacustrine sediments (e.g. Lt-P) (see also section 6.2). It is a potential hazard to development and may be augmented by artificial additions to groundwater from sources such as increased runoff from construction sites or storm sewers, leakage from waterpipes, irrigation, and septic tanks.

9.9 KARST

Underground cavities may exist at shallow depth in rocks such as limestone, dolomite and gypsum (see also section 8.2). Special investigations should be undertaken in order to identify sites of potential collapse and subsidence where intensive development is planned in areas of these rock types and areas designated -K on terrain maps.

9.10 EARTHQUAKES

Earthquakes are potentially the most destructive force affecting the earth's surface. Ground shaking during an earthquake results in damage to buildings and other structures. It may also trigger rockslides or other slope failures, and induce subsidence* or liquification* of certain kinds of unconsolidated materials. Adoption of appropriate standards for construction in seismically active zones can reduce earthquake hazard, and areas susceptible to subsidence or liquification can be avoided. Little can be done however, with regard to slope failures (other than precautions already outlined, section 9.2.1) due to the large number of unknown factors involved.

Seismological records for the East Kootenay region and a seismic risk analysis were obtained from the Earth Physics Branch of Canada Department of Energy, Mines and Resources. Results suggest that earthquakes constitute only a minor hazard in the East Kootenay region. Tremors originating from epicentres* within this area are relatively weak and infrequent. Between 1955 and 1976, 25 local[1] events were recorded with magnitude from 2 to 3.5 on the Richter scale* (Appendix D, Table D.1). Earthquakes with more distant epicentres but greater magnitude are much more significant.

During the period 1899 to 1977 the region[2] was subjected to a total of 2071 earthquakes (Table D.2). The vast majority of these were detectable only by seismic instruments (intensity I on the modified Mercalli scale*, Table D.3), but 73 events were of sufficiently great intensity that they could have been noticed by human beings (intensities II to V) (Figure 9.1). Their magnitude ranges up to 8.6 on the Richter scale. The epicentres of many of these earthquakes are concentrated in a belt which extends southeastward from southeastern British Columbia, through Flathead Lake and Butte, Montana, to about 45°N. Other epicentres are widely scattered along the coasts of British Columbia and Alaska to 60°N.

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[1] Within those parts of British Columbia and Alberta that are bounded by 114°W and 116°W and 49°N and 51°N.

[2] Data applies to a representative site located at 50°N, 115°W.

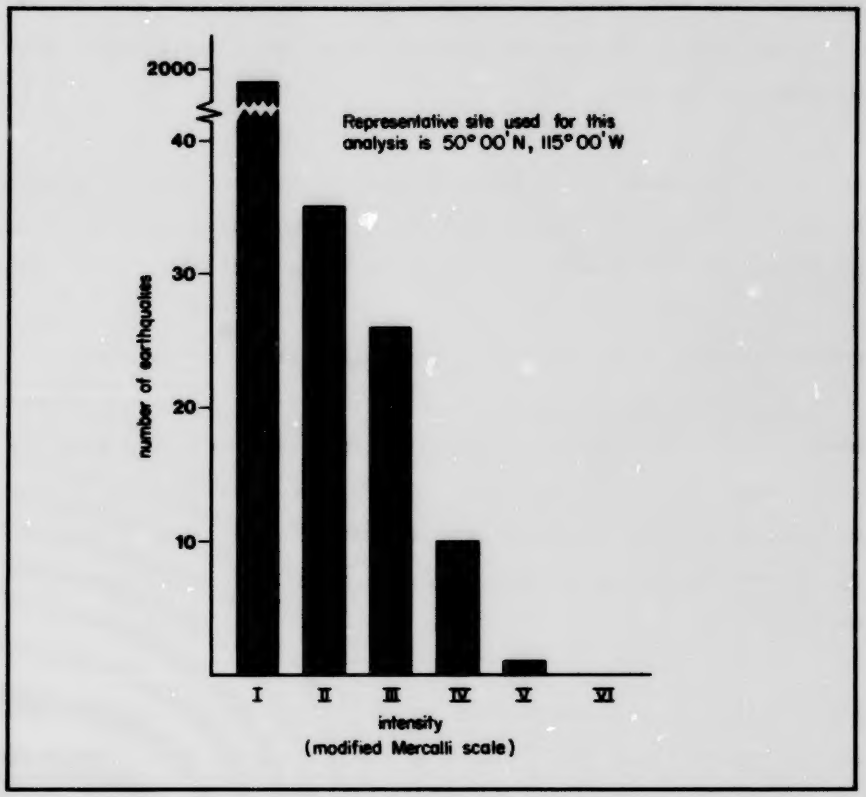


Figure 9.1 Frequency diagram to show total number of earthquakes affecting a site representative of the East Kootenay region (50°N, 115°W) between 1899 and 1977. Total number of earthquakes = 2071.

In order to ascertain the impact of some of the larger earthquakes (intensities IV and V), local newspapers were examined. Only one event appears to have been sufficiently notable to be recorded. This was the Hegben Bridge, Montana earthquake of August 18, 1959. It was recorded as intensity IV in the East Kootenay region, and magnitude 7.10 on the Richter scale. The Fernie Free Press for August 20, 1959 records that the town was shaken for about half a minute "but the shock was not severe. Main effects were swinging doors, heaving beds and a few cases of moving furniture. A few people were mildly scared". The Lake Windermere Valley Echo for the same date reported that the earthquake "...alarmed a few people slightly, but most residents said Tuesday that they knew nothing about it. Most spectacular result was at Radium Hot Springs where park attendants cleaning the cool pool during the night noticed that the water was muddy. Unaware of any subterranean disturbances they were amazed to find that the hot pool was even muddier...relief that the waters still flowed freely, if anything slightly faster and slightly hotter than before. By Wednesday the water was clearing".

The most severe earthquake of all those recorded for the area does not appear to have been noted by the local press. It occurred in April 7, 1972 in the general vicinity of upper Elk River valley (about 50° N). It has a magnitude of 3.4 and an intensity of V.

A statistical analysis of the 1899 to 1977 earthquake data was carried out by the Earth Physics Branch in order to estimate possible levels of earthquake activity in the near future, (W.G. Milne, personal communication, 1979). This is a standard procedure that can be applied to any regional set of seismological data. The results are given in Table 9.1. They indicate, for example, that on average, an earthquake of intensity greater than III will occur once every 10 years. Estimates for return periods of 100 years or greater are probably not reliable due to the scarcity of large earthquakes in the record.

The seismic zoning map of Canada (Whitham et al., 1970) which has been incorporated into the National Building Code of Canada (1977) shows that the East Kootenay region lies within the lowest of four earthquake risk zones (Zone 0). The analysis described above however, which includes more recent data, suggests that it should actually be within Zone 1. (The 100 year return period earthquake has an acceleration amplitude* of between 1% g and 3% g). Methods for incorporating this information into specifications for construction are described in the National Building Code (1977).

Within the study area, local variations in ground acceleration will occur during an earthquake due to differences in amplification of seismic vibrations by various earth materials. In general, bedrock and dry, compact surficial materials will be least affected, whilst thick deposits of loose, coarse or fine textured materials will be most affected. The distribution of materials susceptible to liquification (saturated sands and silts) has not been specifically studied. In view of the relatively low earthquake risk for the region as a whole, further investigation is not warranted at this time, although development plans should always take these factors into account.

TABLE 9.1:

EARTHQUAKE PREDICTIONS FOR A REPRESENTATIVE SITE
(50°N, 115°W) IN THE EAST KOOTENAY REGION

Probability of Acceleration Being Exceeded in One Year	Acceleration as % Gravity	Intensity (Modified Mercalli Scale)	Equivalent Return Period (Years)
0.333	0	II	3
0.100	0	III	10
0.033	1	IV	30
0.020	1	V	50
0.010	2	V	100
0.005	2	VI	200

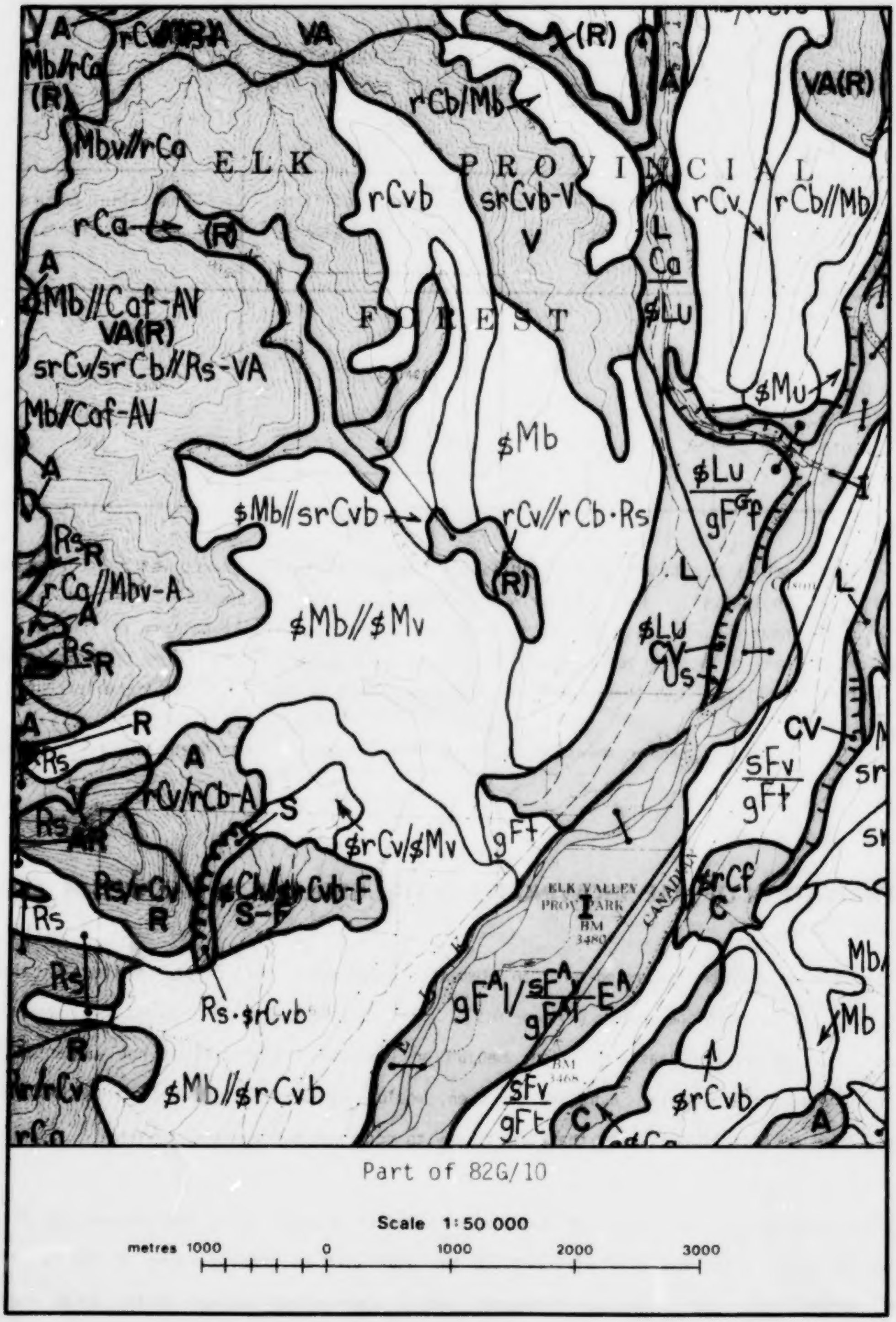
These values are based upon a statistical analysis of earthquakes which occurred between 1899 and 1977 (inclusive). The data provide an estimate of the possible level of earthquake activity in the near future, assuming a continuation of the statistical pattern of the past years. Although predictions of acceleration levels may be made for many probabilities of exceedance, the results for probabilities less than one in one hundred should be used with considerable caution.

(Data, analysis, and comments from Earth Physics Branch, Department of Energy, Mines and Resources, 1979).

9.11 DERIVATION OF MAP SHOWING POTENTIAL GEOLOGICAL HAZARDS

A terrain map may be converted into an elementary geological hazards map by identification and delimitation of hazard-prone areas (Figure 9.2). The various types of potential hazards can be indicated, but rating of areas with high, medium or low hazard potential is not warranted on the basis of information available. A hazard map then, would simply indicate the distribution and types of destructive geological processes that are likely to occur within a given region.

It is recommended that users of terrain information prepare their own hazard map for their areas of interest. This exercise will provide the user with an understanding of the relationship between terrain units and geological processes, and a clear visualization of the areas where they


ELK PROVINCIAL FOREST
VA
(R)
VA(R)
rCb/Mb
Mbv//rCa
rCvb
srCvb-V
V
rCv
rCb//Mb
rCa
Mb//Caf-AV
srCv/srCb//Rs-VA
Mb//Caf-AV
L
Ca
$Lu
$Mu
$Mb
$Lu
gF
$Mb//srCvb
rCv//rCb·Rs
rCa//Mbv-A
$Mb//$Mv
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gFt
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S-F
Rs·$rCvb
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ELK VALLEY PROV PARK
BM 3480
CANADIAN
$rCf
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Mb
$rCvb
A
C
Part of 82G/10
Scale 1:50 000
metres 1000
0
1000
2000
3000

Figure 9.2 Example of derivative map for geological hazards and legend.

LEGEND

SYMBOL	POTENTIAL HAZARD
S	rockslide deposit or potential rockslide
R	rockfall
C	debris flow, mudflow, earthflow
A	avalanches
V	gullying
D	wind erosion
I	fluvial processes: innundation, shifting channels, bank erosion
L	processes associated with lacustrine silt:- L-F, failing; L-P, piping; L-V, gullying
K	Karst: limestone solution
F or -F	failing

occur. Terrain unit symbols and on-site symbols which designate hazard-prone terrain units are listed in Table 9.2. These units and hazard types can be marked on an overlay, as in Figure 9.2, or they can be colour-coded on the basic terrain map. Where hazardous terrain is shown as one component of a composite unit, (e.g. $\underline{gF^{A}l}$/Mb or Mbv/Cv//$\underline{Rs}$), then the whole unit should be identified on the derivative map. However, provision should be made for distinguishing between cases where hazards affect large or small proportions of the total area of the terrain unit, in accordance with the definition of composite unit symbols (Appendix B.7). This is done in the example shown in Figure 9.2

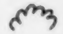
The following points should be born in mind when preparing and utilizing the hazard map.

1. This derivative map is no more accurate than the original terrain map (section 3.4), and possibly less so, since the chief criterion of the basic mapping was origin of materials rather than active geological processes. On no account should such a map be used to indicate the safety of specific sites or small areas, such as subdivisions or campsites. It should be referred to for regional planning purposes, such as selection of corridors for roads or transmission lines, or for preliminary identification of general areas for townsites or industrial sites.
2. The potential hazards that are implied by terrain unit symbols may not affect the whole area within the unit. For example, in a Mvb-A terrain unit there may well be 'safe' areas inbetween avalanche tracks. The map merely indicates that avalanches (or rockfalls, debris flows, floods...) occur somewhere within the designated area. This is most obviously the case in composite units where a symbol such as $gF^{A}l/gFt\text{-}E^{A}$ indicates that part of the area ($gF^{A}l$, $-E^{A}$) is subject to floods and shifting channels, but the remainder (gFt) is dry and stable. More detailed mapping could separate those areas that are directly threatened by hazards from those that are not.

The existence of a hazard condition within a terrain unit should be interpreted as either "this area should be avoided" or "this area requires more detailed mapping and further investigation (geological, geotechnical, hydrological) before its capability for any kind of development can be assessed". The former reasoning will probably apply where adjacent or alternate non-hazardous areas are available for utilization, and the latter where constraints (physical, social, or economic) already exist in other areas.

TABLE 9.2

GUIDE TO IDENTIFICATION OF TERRAIN UNITS SUSCEPTIBLE TO GEOLOGICAL HAZARDS

Terrain Unit Symbol[1] (alphabetical order by genetic material)	Geological Process	Comments
a,rCh,u,r	rockslide	- indicates rockslide deposit; site may be prone to further rockslides
a,rCa,f some (nt)Ca,f	rockfall	- depositional area (talus); site may receive further rockfall
s,g,dCa,f srCa,f some (nt)Ca,f	debris flows mudflows	- depositional area; further flows may occur
(at) Ca,f-A,-AV (at) Cv,b-A,-AV	avalanches	- avalanche tracks and gullies followed by avalanches
(at) Ca,b,v-V	gullying	- includes erosion by running water, and/or debris flows, and/or small slumps and slides
s,sEv,b,m dune on-site symbol	wind erosion (deflation)	- likely to occur if vegetation cover absent - see -D below
(at) $F^{A}l$,f (at) Fl,f any F unit $-E^{A}$	inundation, shifting channels bank erosion	
c,s,sLs,t c,s,$sL^{G}s$,t	slumps, earthflows, falling blocks	- applies to all scarps in lacustrine units
any L unit -P	piping	- likely to occur close to scarps and gullies but probably not extensively developed
any L unit -F	slope failure in progress	- slumps, slides and earthflows
any L unit -V	gullying	- includes erosion by running water and instability along steep gully walls
(at) Mbv-V	gullying	- includes erosion by running water, and/or debris flows, and/or small slumps and slides
Rs	rockfall	- source area; sites downslope may be vulnerable
Rs-G	frost shattering and rockfall	- source area; sites downslope may be vulnerable
any R unit -F	slope failure in progress	- rockslide site
R-K	solution (karst)	- underground cavities; collapse and subsidence
Us Us-V,F	slumps, slides, gullying	- may also include potential earthflows and debris flows
Modifying Processes Applicable to any Terrain Unit		
-A	avalanches	
-D	wind erosion	- (deflated)
-F	slope failure in progress	
On-site Symbols		
(scarp)	slope processes	- see Us and Rs above
 (landslide scar)	slope failure site	- may be prone to further slides
(dunes)	wind erosion	
Ⓚ	solution (karst)	- see R-K above

[1] The use of a comma (,) between symbols indicates that either one, two, or all of these symbols may be present.

Also: (nt) - no texture symbol specified on terrain map
(at) - any texture symbol specified on terrain map

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Appendices

Appendix A

GLOSSARY

ABANDONED SHORELINE, STRANDLINE
A former shoreline or beach formed by sea or lake level higher than at present.

ACCELERATION AMPLITUDE
A means of measuring the shaking involved in an earthquake.

ALLUVIAL (FLUVIAL) FAN
Fan consisting chiefly of fluvial gravels and sand; (section 5.3.3).

ALLUVIAL (COLLUVIAL) FAN
Fan consisting chiefly of debris flows; (section 7.6).

ANGLE OF REPOSE
Angle which non-cohesive granular material will naturally assume; 30-35° for most talus deposits.

ANTICLINE
An upfold resulting from compression of sedimentary strata; rock layers dip away from centre line.

AQUIFER
A permeable rock formation or layer of unconsolidated material with horizontal or gently inclined layers that stores and transmits groundwater in sufficient quantity to supply wells.

ARÊTE
A jagged, sharp ridge formed where two cirque walls intersect from opposite sides.

ARGILLITE
A fine-textured rock that has undergone a somewhat higher degree of induration than is present in siltstone, claystone, or shale; argillite holds an intermediate position between those rocks and slate; cleavage is approximately parallel to bedding.

BATHOLITH
A large (at least 100 km^2 in area) body of intrusive igneous rock; the rock is generally coarse-grained due to slow cooling; batholiths form in the cores of many mountain ranges.

BEARING STRENGTH
The average load per unit area that is required to rupture a supporting mass of material.

BRAIDED REACH, CHANNEL
A stream flowing in several channels that divide and reunite; resembling strands of a braid.

BOG
An area covered or filled with peat materials; watertable is generally high and the bog surface is slightly elevated.

BULK DENSITY
The mass of dry soil or sediment per unit bulk volume; the bulk volume includes both solids and pore spaces of soil or sediment mass.

CALCAREOUS
Containing calcium carbonate ($CaCO_3$, calcite).

CARBONATE ROCK
A rock composed of carbonate minerals; most commonly limestone or dolomite.

CHLORITE

Group of minerals having a general composition of hydrated silicates of aluminum, ferrous iron and magnesium; they are structurally similar to micas and of a greenish colour.

CIRQUE

Formed by glacial erosion, and consisting of a rounded basin, partially enclosed by steep cliffs and may contain a small lake (tarn) or cirque glacier.

CIRQUE GLACIER

A small glacier found in a cirque; usually the first to form and last to melt in a period of glaciation.

COLLAPSE SINKHOLE

Caverns may become so enlarged by solution and erosion that they locally collapse, giving rise to depressions in the ground surface.

COLLUVIUM

Material that has moved downslope due to gravity; includes landslide deposits, talus material and earthflows.

CONGLOMERATE

A sedimentary rock consisting of rounded stones in a matrix of sand; consolidated equivalent of gravel.

CRAG AND TAIL

A streamlined glacial feature consisting of a resistant rock knob with till deposited in a downstream shadow region.

CRETACEOUS

Subdivision of geological time; (see legend to Figure 2.1).

CROSS-BEDDING

Inclined bedding between the main bedding planes.

CUMULIC

Layer of sandy, silty or clayey material over an organic soil.

DIAMICTON

Poorly sorted unconsolidated deposit containing significant amounts of both fines (silt and clay) and gravel-sized particles; particle size distribution is bi-modal with a peak in both these size classes.

DIP

Inclination of bedding measured from horizontal.

DOLOMITE

A carbonate mineral of composition $CaMg(CO_3)_2$, calcium-magnesium carbonate; where this predominates, the rock itself is called dolomite.

DOWNFAULTED, DOWNTHROWN BLOCK

In a normal fault movement is predominantly in a vertical direction so that one side is raised (upthrown) relative to the other, which is downthrown.

DOWNWARPED

An area that has been relatively depressed by bending rather than faulting of strata.

DRIFT

A collective term for all unconsolidated materials associated with glaciation.

DROPSTONES

Ice-rafted stones transported by floating ice; when released by melting they settle to the lake floor and become embedded in fine-textured lacustrine sediments.

DRUMLIN

A streamlined hill or ridge composed of glacial till with long axis paralleling the direction of flow of a former glacier; long profile is typically asymmetrical with the steep side facing up glacier, thus enabling the direction of ice movement to be determined.

EPICENTRE

The point on the earth's surface directly above the focus of an earthquake; the focus is the point at which the rupture occurs.

ESCARPMENT

Steep face extending laterally for some distance.

ESKER

Sinuous gravel ridge; (section 5.3.5).

FAULT SCARP

Cliff formed by a fault.

FLAT-IRON

A triangular-shaped, sloping mesa-type of hogback ridge, often occurring in series on the flank of a mountain.

FLOODPLAIN

Flat area adjacent to river that is periodically flooded; (section 5.3.1).

FLUTING

Smooth, gutter-like channels or deep smooth furrows worn in surface of rocks or till by glacial movement, normally parallel to direction of ice flow.

FLUVIAL

Pertaining to rivers and streams; (see Chapter Four).

FLUVIOGLACIAL

Pertaining to glacial meltwater streams; (see Chapter Four).

FRASER GLACIATION

Local name for the last major glaciation in B.C. extending from approximately 29 000 years B.P. (before present, absolute age in years) to 10 000 years B.P.; it is considered to be equivalent to the Late (Classical) Wisconsin Glaciation of central North America.

GEOLOGICAL (GEOMORPHOLOGICAL) PROCESSES

The chemical and physical interactions between natural forces and the earth's surface which modify the earth's surface form, e.g. erosion by water, landsliding, weathering.

GLACIOLACUSTRINE

Pertaining to lakes dammed by glaciers; refers to lacustrine sediments deposited close to glacier ice.

GRANODIORITE

An intrusive, igneous, medium to coarse-grained crystalline rock; consists of quartz and feldspar with biotite, hornblende, or pyroxene as mafic constituents; is intermediate between quartz monzonite and quartz diorite.

GYPSUM

Soft white mineral, (hydrous calcium sulphate), used in the manufacture of plaster of Paris; it is an evaporite, which is a salt precipitated from shallow or constricted water bodies where evaporation is rapid; commonly interlayered with shales and limestones.

HARDNESS OF ROCK

Resistance to scratching or abrasion.

HORN

Where three of more cirques grow together, a sharp-pointed peak is formed by the intersection of arêtes.

HYDROCOMPACTION

Decrease of volume and corresponding increase in density that occurs upon wetting of a sediment.

HYDROLOGIC REGIME
Systematic change of hydrologic conditions with time; annual and seasonal fluctuations of soil moisture and river discharge.

IGNEOUS ROCK
Formed by solidification of hot mobile material (magma); if it solidifies at depth, cooling is slow and large crystals can form (intrusive or plutonic rock); volcanic or extrusive rock cools quickly at the surface of the earth, large crystals do not have time to grow, and the rock is fine-grained.

IMPERMEABLE
Opposite of permeable.

IMPERVIOUS
Opposite of permeable.

IN SITU
In its natural and original position or place.

KAME
Hummocky, ice-contact deposits; (section 5.3.5).

KAME TERRACE
Irregular, ice-contact deposit; (section 5.3.5).

KARST
Landforms resulting from solution of carbonate rocks; (section 8.2).

KETTLE
A small hollow or depression formed in glacial deposits where outwash was deposited around a residual block of ice that later melted.

KNOB AND KETTLE
Moraine or fluvioglacial deposits that appear as a belt of knobby hills interspersed with basin like hollows (kettles), some of which hold small lakes; also called knob-and-basin or kame-and-kettle topography.

LACUSTRINE
Pertaining to lakes; (see Chapter Five).

LARAMIDE OROGENY
Period of mountain building in late-Cretaceous to early Tertiary time.

LIMESTONE
A sedimentary rock consisting chiefly of calcium carbonate; it is the consolidated equivalent of limy mud, calcareous sand, or shell fragments.

LIQUEFACTION
Sudden large decrease of shearing resistance of a cohesionless soil or sediment; caused by a collapse of soil structure due to shock or other strain, and is associated with a sudden, temporary increase of interstitial water pressure; it involves a temporary transformation of material into a fluid mass.

LOESS
Material transported and deposited by wind and consisting of predominantly silt-sized particles.

LONGITUDINAL VALLEY
A valley that runs parallel to the strike of inclined rocks or faults, or at 90° to dip.

MARL
A calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells.

MASSIVE
Unconsolidated material or bedrock in which bedding planes are absent or widely spaced.

MASS WASTING
Slow, downslope movement of rock debris; also used in a more general sense to refer to the variety of processes whereby the land surface is slowly lowered.

MEANDERING REACH, MEANDERS
Section of a stream containing broad semicircular curves that develop as the stream erodes the outer bank of a curve and deposits sediment against the inner bank; as this progresses the meander bends grow, until eventually the channels meet causing the intervening meander loop to be pinched off and abandoned thus forming a cut-off or oxbow lake.

MELTWATER
Water derived from melting glacier ice; (section 5.3.4).

MESOZOIC
A subdivision of geological time; (see legend to Figure 2.1).

MERCALLI SCALE
Scale of earthquake intensity; (see Appendix D.3).

METAMORPHIC ROCK
Rocks which have formed in the solid state by modification of pre-existing rocks in response to pronounced changes of temperature, pressure and chemical environment, usually deep within the earth's crust; may form from igneous, sedimentary, or metamorphic rocks; examples include quartzite, slate, schist, phyllite.

MORAINE
Material deposited directly by glaciers; (section 3.1).

NEOGLACIATION
The rebirth and/or growth of glaciers following maximum shrinkage during the Hypsithermal (approx. 9000 years B.P. to 6000 years B.P. in B.C.) Interval. Glaciers reached their maximum Neoglacial extent during the past several centuries, and have receded from Neoglacial terminal moraines during the last 100 to 200 years.

NORMAL FAULT
Has a steep or nearly vertical fault plane; movement is mainly in a vertical direction so that the block above the fault has moved downward relative to the block below.

OUTWASH
Material or landform created by meltwater flowing away from a glacier; (section 5.3.4).

PEDOGENIC PROCESSES
Soil-forming processes that result from interaction of physical, chemical and biological effects on bedrock or unconsolidated materials at the earth's surface.

PERMEABILITY
The ability of a substance to transmit fluids and gases; governed by size and shape of pores, size and shape of their interconnections, and extent of the latter. Coarse sands or gravels permit rapid water flow and are thus highly permeable. Clays and rocks containing much clay have microscopic pores which impede the flow of water so effectively that they are termed impermeable.

PIPING
Subsurface erosion in particulate materials; (section 6.2).

POROUS
Porosity refers to the total volume of pore space present in a given volume of rock or other material; it is a measure of the amount of water that can be held in storage. Coarse-grained rocks can have high porosity; sands and gravels are highly porous whereas shale, because it is compact, is relatively low in porosity. Soft clay or mud has high porosity even though the pores are extremely small.

PROGLACIAL ENVIRONMENT
The area in front of a glacier; deposits are generally fluvioglacial, glaciolacustrine, or glaciomarine.

PROTEROZOIC
A subdivision of geological time; (see legend to Figure 2.1).

QUARTZ MONZONITE
A coarse grained, crystalline, plutonic rock containing major orthoclase and plagioclase (in approximately equal amounts) and quartz.

QUARTZITE
A tough massive rock consisting almost wholly of quartz and usually having a pale colour; product of metamorphism of pure sandstone.

QUATERNARY
The most recent (and present) episode of geological time; (see legend to Figure 2.1).

RIPPLE MARKS
Undulating surface or bedding plane in non-cohesive granular materials produced by wind or water currents.

RICHTER SCALE
Range of numerical values for earthquake magnitude; logarithmic scale related to amount of energy released by earthquake.

ROCK GLACIER
A glacier-like mass of rubble and blocks; (section 7.7).

SANDSTONE
A sedimentary rock with predominantly sand-sized particles.

SCHIST
A medium or coarse-grained metamorphic rock with sub-parallel or parallel orientation of platy micaceous minerals which dominate its composition. Such a property of foliation gives rise to the term "schistosity".

SCROLL PATTERN
Arc-shaped depressions or ridges of former meanders or river banks forming a repetitive pattern on a floodplain.

SEDIMENTARY ROCK
Rocks formed by accumulation and cementation of sediment that has been moved by water, air or ice, or precipitated from a solution; characterized by layered structure known as bedding or stratification. Examples: conglomerate, shale, limestone, dolomite.

SERICITE
A fine-grained variety of mica, usually muscovite, occurring in small scales, especially in schists.

SHALE
A thinly bedded sedimentary rock with predominantly clay-sized particles.

SINKHOLE
A small, steep depression caused in karst topography by collapse of caverns.

SLOPE FAILURE
Collapse and downslope movement of bedrock or unconsolidated material that occurs when gravitational forces exceed resisting forces.

SLOPEWASH
Process or material involved with downslope movement of particles due to gravity assisted by running water that is not concentrated in channels.

SLUMP STRUCTURES

Contortions, folds and fractures in layered sediments that result from downslope movement.

SOIL: PEDOLOGIC SOIL

Uppermost layer of the earth's surface with morphology and properties resulting from the effects of climate, flora, fauna, parent materials (rock and surficial deposits), topography, and time. Its lower limit is the lower limit of soil forming processes which, in British Columbia, is usually at 1 to 2 metres depth.

SOIL: ENGINEERING SOIL

Refers to the entire mantling cover of loose earth materials on the surface of the earth regardless of origin, including surficial deposits and pedologic soil.

SOIL CREEP

Imperceptible downslope movement of loose, surficial materials; (section 7.2).

STRIAE

Scratches left on bedrock and boulders by overriding glacier ice; show direction of ice motion.

SYNCLINE

A downfold in sedimentary rocks in which the strata dip inward from both sides toward the axis.

TARN

A small mountain lake or pool on the floor of a cirque.

TALUS

Angular rock fragments that accumulate from rockfall at the foot of cliffs; (section 7.3).

TECTONIC

Rock structures and external forms resulting from deformation of the earth's crust.

TERMINAL MORAINE

A ridge of unsorted till deposited by a glacier at the line of its farthest advance.

TERTIARY PERIOD

A subdivision of geological time; (see legend to Figure 2.1).

THRUST FAULT

Involves predominantly horizontal movement; fault plane is in a near-horizontal position, and one slice of rock rides up over the adjacent ground surface.

THRUST SHEET

The block above a thrust fault.

TILL

Material deposited directly by glacier ice; (see Chapter Three).

TRANSVERSE FAULT

A fault whose strike or trend is transverse to the general rock structure.

TRANSVERSE VALLEY

A valley having a direction at right angles to the strike of the rocks.

WEATHERING

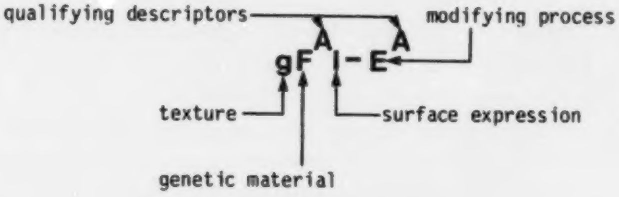
A group of physical, chemical and biological processes whereby rocks or unconsolidated materials, on exposure to the weather, change in character and decompose or disintegrate.

Appendix B

LEGEND FOR EAST KOOTENAY TERRAIN MAPS

B.1 EXPLANATION OF LETTER NOTATION

A combination of letters is used to designate each map unit. The relative position of letters within the symbol indicates the characteristic that they represent.



Units consisting of two or more types of terrain are designated by two or more groups of letters separated by dots and slashes:-

e.g. gFt/dCf (see Composite Units below)

Material underlying the surface unit is shown by a symbol that is written beneath the surface unit symbol and separated from it by a horizontal line:-

e.g. $\frac{\text{sEv}}{\text{gFt}}$

B.2 GENETIC MATERIALS

LETTER SYMBOL	NAME (PROCESS STATUS[1])	DESCRIPTION
A	anthropogenic (A)	man-made or modified materials including those associated with mineral exploitation and waste disposal.
C	colluvial (A)	products of mass movement; includes rubbly bedrock-derived material and material derived from unconsolidated Quaternary sediments, includes earthflow, mudflow and landslide deposits and talus material. generally consists of massive to moderately well stratified sediments with a great range of particle sizes.

---

[1] See Qualifying Descriptors below for definition of Process Status.

B.2 (CONT'D)

LETTER SYMBOL	NAME (PROCESS STATUS[1])	DESCRIPTION
E	eolian (A)	materials transported and deposited by wind; includes dunes, loess and sheets of sand and silt. generally consists of medium to fine sand and coarse silt that is well-sorted and poorly compacted.
F	fluvial (I)	material transported and deposited by streams and rivers; alluvial materials. generally consists of moderately- to well-bedded and moderately- to well-sorted gravels and/or silt.
F^G	fluvioglacial (I)	fluvial materials that were deposited either in contact with or directly in front of glacier ice. generally consists of non-bedded to poorly-bedded and non-sorted to poorly-sorted gravels with minor amounts of sand; evidence of collapse associated with melting ice (slump structures, kettles, irregular topography) is commonly present; includes kames; kame terraces, eskers and pitted outwash.
I	ice (A)	permanent snow and ice; glaciers.
L	lacustrine (I)	sediments that have accumulated in lakes. generally consists of stratified and sorted sand, silt and clay, and moderately- to well-sorted, rounded gravels that are the products of lake-shore wave action.
L^G	glaciolacustrine(I)	lacustrine materials that were deposited in contact with, or directly from melting glacier ice. typically consists of stratified silt and sand with slump and settling structures and with scattered (ice-rafted) stones; surface is irregular and/or kettled.
M	morainal (I)	material deposited directly by glaciers; till Generally consists of compact, non-sorted and non-stratified material that contains a wide range of particle sizes and a matrix of silt or clay.
O	organic	material resulting from the accumulation and decay of vegetative matter. generally consists of peat, unstratified and locally containing minor amounts of marl and inorganic detritus.

B.2 (CONT'D)

LETTER SYMBOL	NAME (PROCESS STATUS[1])	DESCRIPTION
O^B	organic (bog) (A)	peat material consisting of undecomposed to moderately decomposed sphagnum mosses; water-table is generally high; dominant vegetation is black spruce, feathermosses, sphagnum spp. and ledum spp.
O^F	organic (fen) (A)	peat material consisting of well to moderately decomposed sedges (carex spp.); watertable is commonly at the surface; vegetation dominantly consists of sedges, grasses and reeds with some shrub cover.
O^S	organic (swamp) (A)	peat material consisting of decomposed sedge or feathermoss species; watertable is generally at or above the surface; vegetation is most commonly a tree cover of cedar and spruce.
R	bedrock (I)	outcrops and rock covered by less than 10 cms of unconsolidated material.
U	undifferentiated (I)	used where more than three types of genetic material occur in close proximity and cannot be separated at the scale of mapping.

B.3 TEXTURE

LETTER SYMBOL	NAME	PARTICLE SIZE (mm)	OTHER CHARACTERISTICS
b	bouldery	>256	rounded and subrounded particles
g	gravelly	2-256	rounded and subrounded particles (includes interstitial sand)
s	sandy	0.625-2	
$	silty	0.0039-0.0625	
c	clayey	<0.0039	
d	diamicton		heterogeneous mixture of particles of any size, roundness or angularity in silt and clay matrix
r	rubbly	2-256	angular and subangular particles with finer interstitial material
a	blocky	>256	angular and subangular particles

B.3 (CONT'D)

Notes:-
1. The absence of a textural term from a unit symbol indicates that texture of the material was not observed in the field and cannot be reliably interpreted from air photos. The reader is referred to the general textural descriptions under the heading Genetic Materials.
2. Where two textural terms are used together, they are written in order of increasing importance, e.g. $s is silty sand, sg is sandy gravel.
3. A diamicton texture is always implied in the case of morainal (M) materials. Any textural term written in the symbol merely modifies this basic texture, e.g. $M indicates till consisting of silty diamicton, not silt alone.

B.4 SURFACE EXPRESSION

LETTER SYMBOL	NAME	DESCRIPTION
a	apron	a relatively gently sloping surface that is at the foot of a steeper slope and underlain by material derived from that steeper slope.
b	blanket	a mantle of unconsolidated material which has no constructional form of its own, but derives its general surface expression from the topography of the unit which it overlies; it masks minor topographic irregularities in the underlying unit and is more than 1 m thick. - if the underlying unit consists of unconsolidated materials, it is shown in the unit symbol; if no underlying unit is shown, it may be assumed to be bedrock.
f	fan	a surface that is a sector of a cone.
h	hummocky	steep-sided hillocks and hollows that are rounded or irregular in plan; slopes of 15 to 35° predominate on unconsolidated materials, and slopes of 15 to 90° predominate on bedrock; local relief is greater than 1 m.
l	level	a flat or gently inclined (less than 5°) surface with uniform slope and local relief of less than 1 m.

B.4 (CONT'D)

LETTER SYMBOL	NAME	DESCRIPTION
m	rolling	elongate or linear, parallel or subparallel hills or ridges with slopes generally less than 15° and local relief of more than 1 m.
r	ridged	elongate or linear, parallel or subparallel hills or ridges with slopes predominantly between 15 and 35° on unconsolidated materials and between 15 and 90° on bedrock.
s	steep	steeply inclined erosional slopes (scarps) with gradients commonly greater than 35° on unconsolidated materials and greater than 35° on bedrock.
t	terraced	step-like topography; includes both scarp face and the horizontal or gently inclined surface above it.
u	undulating	low hills and depressions with slopes generally less than 15° and

B.5 MODIFYING PROCESSES

LETTER SYMBOL	NAME (PROCESS STATUS[1])	DESCRIPTION
A	avalanched (A)	slopes modified by frequent snow avalanches and by the deposition of rock debris transported by snow avalanches.
C	cryoturbated (A)	unconsolidated sediments or colluvium modified by frost heaving and churning; includes patterned ground.
D	deflated (A)	areas modified due to the removal of sand and finer particles by wind action.
E^G	channelled by glacial meltwater(I)	surfaces crossed by glacial meltwater channels; channels on former outwash plains are generally broad and shallow; other meltwater channels are typically narrow, flat-floored, steep-sided troughs.

B.5 (CONT'D)

LETTER SYMBOL	NAME (PROCESS STATUS[1])	DESCRIPTION
F	failing (A)	slopes where slow downslope movement of masses of unconsolidated material or bedrock is occurring; slopes may be crossed by tension fractures, slump scarps, or show other evidence of slow failure; also includes slopes where relatively rapid soil creep is occurring.
G	frost shattered (A)	rock surfaces covered with angular fragments derived in situ by frost shattering.
H	kettled (I)	surfaces marked by depressions formed due to melting of ice blocks in fluvioglacial, glaciolacustrine or morainal sediments.
K	karst (A)	bedrock (chiefly limestone) modified by solution resulting in surface features such as sinkholes and limestone pavement, and subsurface caverns and underground drainage.
N	nivated (A)	surface modified by shallow depressions that result from frost action, meltwater erosion and mass wasting around and under snow patches.
P	piping (A)	surface modified by small, steep-sided depressions, commonly aligned along routes of subsurface drainage; results from collapse of underground conduits formed by removal of particulate matter; ("pseudokarst").
S	soliflucted (A)	surface modified by the slow downslope movement of saturated overburden across a frozen or otherwise impermeable substrate.

B.6 QUALIFYING DESCRIPTORS

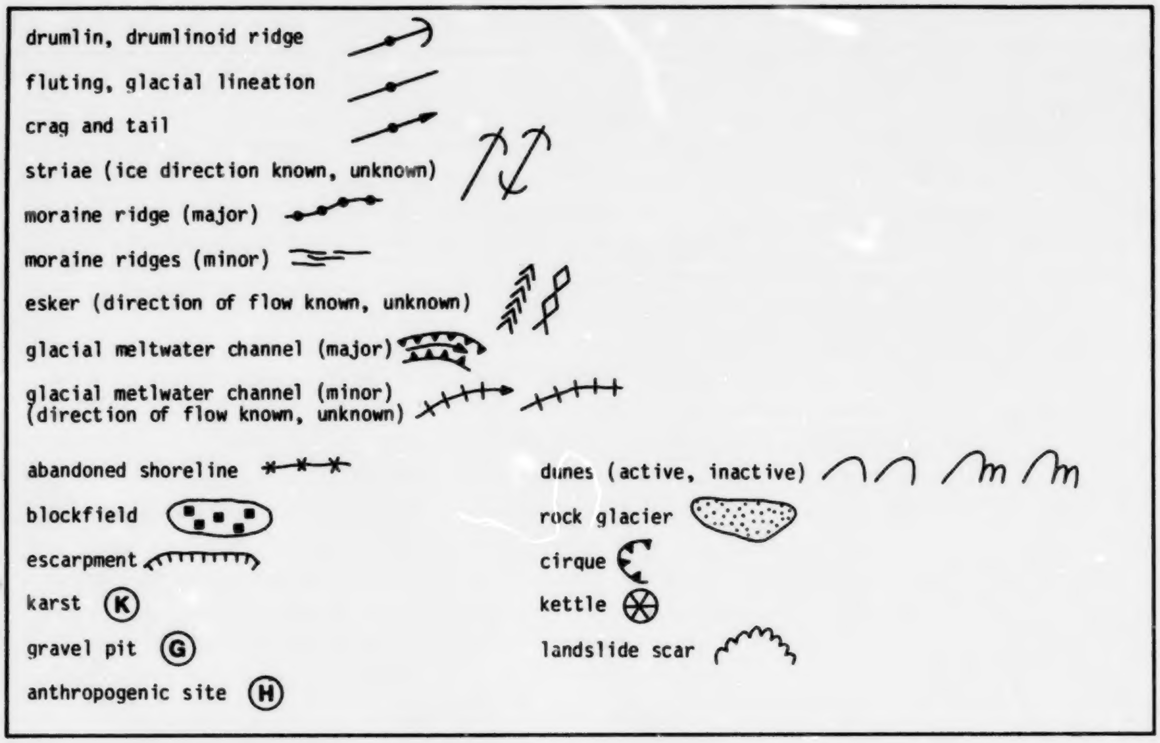
LETTER SYMBOL	NAME	DESCRIPTION
G	glacial	used to qualify non-glacial genetic material or process modifiers where there is evidence that glacier ice affected the mode of deposition of materials or the mode of operation of a process (see F^G, L^G and E^G above).
B,F,S	bog, fen, swamp	used where possible to supply additional information about units of organic material (see O^B, O^F and O^S above).
A, I	active, inactive (process status descriptors)	used to qualify genetic materials and modifying processes with regard to their current state of activity. Active: there is evidence that a modifying process is either operating continuously or is of a recurrent nature at the present time; there is evidence that the process of formation of a genetic material is operative at the present time. Inactive: there is no evidence to suggest that a modifying process is continuing or recurrent; the process of formation of a genetic material has ceased. A process status descriptor is designated for each genetic material and for each modifying process on the basis of their most common state of activity at the present time. (See process status column in Genetic Materials and Modifying Processes above). Process status descriptors are shown in unit symbols on the map only where the current state of activity is contrary to the designated state.

B.7 COMPOSITE UNITS

Composite units are employed where two or three types of terrain are intermixed or occupy such small areas that they cannot be designated as separate units at the scale of mapping. Symbols (defined below) are used to indicate the relative amounts of each terrain type, and the components are always written in decreasing order of importance.

	.	the components on either side of this symbol are approximately equal.
	/	the component in front of the symbol is more extensive than the one that follows.
	//	the component in front of the symbol is considerably more extensive than the one that follows.
e.g.	Mb//R	Mb is considerably more extensive than R.
	Mb//R.Cv	Mb is considerably more extensive than R; R and Cv are of roughly equal extent.
	Mb/R//Cv	R is less extensive than Mb; Cv is considerably less than R.

B.8 ON-SITE SYMBOLS


drumlin, drumlinoid ridge
fluting, glacial lineation
crag and tail
striae (ice direction known, unknown)
moraine ridge (major)
moraine ridges (minor)
esker (direction of flow known, unknown)
glacial meltwater channel (major)
glacial metlwater channel (minor) (direction of flow known, unknown)
abandoned shoreline
blockfield
escarpment
karst
K
gravel pit
G
anthropogenic site
H
dunes (active, inactive)
rock glacier
cirque
kettle
landslide scar

Appendix C

CHARACTERISTICS OF TILLS

C.1 PARTICLE SIZE DISTRIBUTION

Till samples for particle size analysis were collected from some parts of the East Kootenay region. Particle size distribution of till matrix material (less than 8 mm fraction) was determined by sieving and pipette analysis. Results for Wycliffe, Cedrus, Flathead and Purcell tills are presented in Figures C.1 to C.4; results for a variety of lithologically controlled tills in the Kootenay Ranges are presented in Figure C.5.

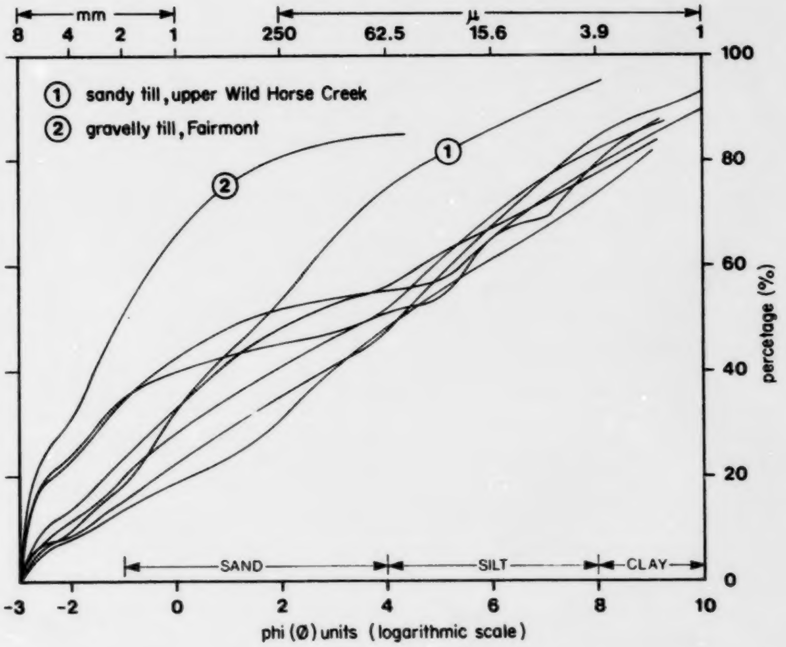


Figure C.1 Particle size distributions: matrix of Wycliffe till.

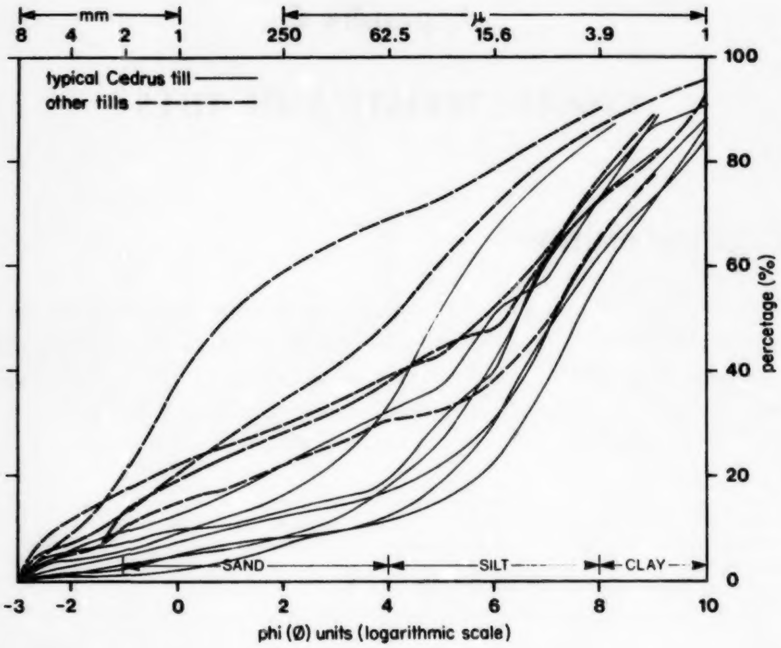


Figure C.2 Particle size distributions: matrix of Cedrus till and associated tills.

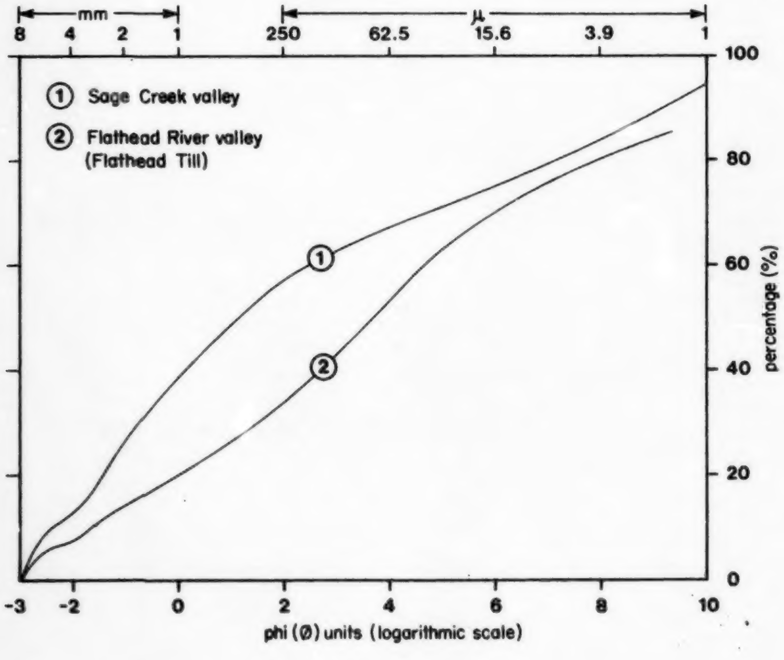


Figure C.3 Particle size distributions: matrix of tills in Flathead Basin.

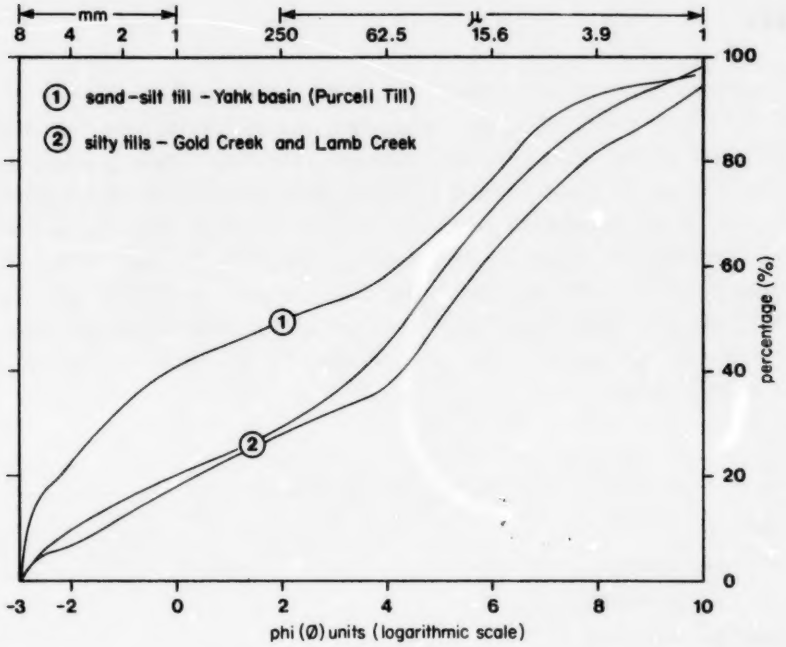


Figure C.4 Particle size distributions: matrix of tills from Purcell Mountains.

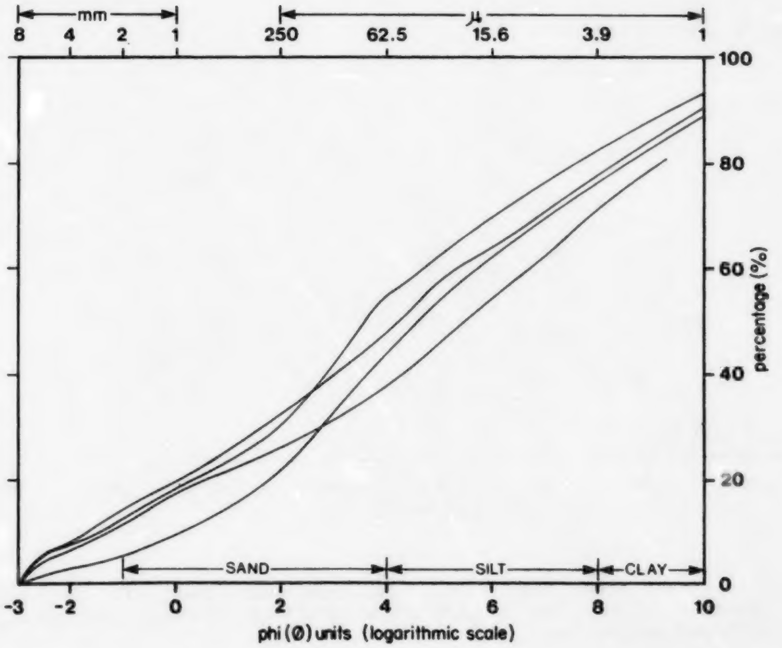


Figure C.5 Particle size distributions: matrix of tills from the Kootenay Ranges.

C.2 PLASTICITY

Atterberg (plastic and liquid) limits for till samples are shown in Table C.1 and Figure C.6[1] (cf. Flawn, 1970, pp. 70-72; Yong and Warkentin, 1966, pp 94-99). In general the tills are of low plasticity and low compressibility. This probably results from the relative scarcity of clay minerals in these comparatively young and unweathered geological materials. There appears to be no systematic variation of these properties with till texture, bedrock lithology, or till type (as described in Section 4.4 of this report). The highest liquid limit and plasticity index (liquid limit minus plastic limit) values were obtained from some Cedrus and Elk Valley tills, possibly reflecting their derivation from phyllites and shales which are susceptible to rapid weathering and release or formation of clay minerals.

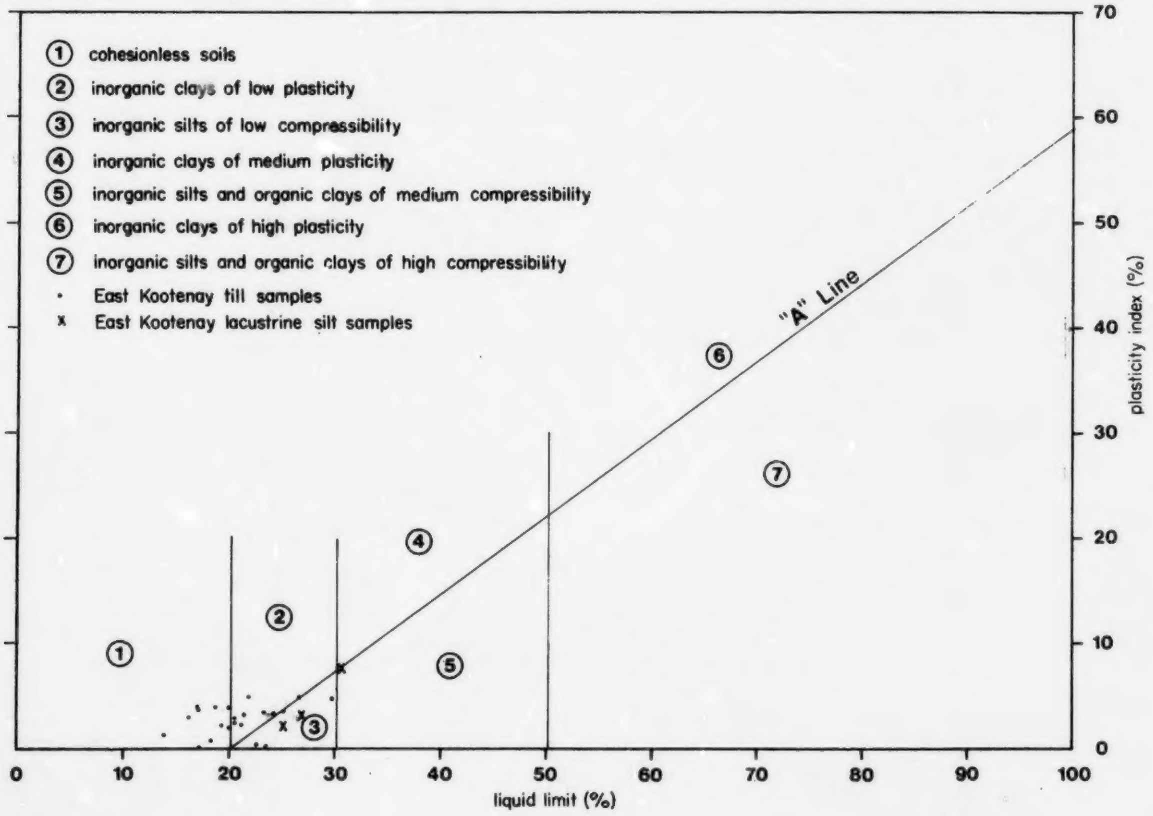


Figure C.6 Plasticity chart from Legget (1967) and Casagrande (1948) with data superimposed for East Kootenay tills. The "A" line is an empirical boundary that separates sediments with different properties.

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[1] Includes data collected by L. Lacelle, Soils Unit, Terrestrial Studies Branch.

TABLE C.1:

ATTERBERG LIMITS AND PLASTICITY INDEX FOR EAST KOOTENAY TILLS

Sample Number	Location/ Till Type	Plastic Limit	Liquid Limit	Plasticity Index	Less than 2mm Fraction			Bedrock Geology
					Sand	Silt	Clay	
76-1	Cross R valley (Park Ranges)	12.65	15.83	3.18	31	42	27	limestone & phyllite
76-5	Upper Lussier R valley (Kootenay Rngs)	15.73	19.84	4.11	23	46	31	limestone & shale
76-8	Cedrus till	17.46	20.35	2.89	26	41	33	phyllite, limestone
76-17	Cedrus till	21.27	24.88	3.61	22	41	37	phyllite, limestone
76-20	Cedrus till	21.63	26.48	4.85	15	60	25	phyllite, limestone
76-25	Wycliffe till	13.03	16.82	3.79	-	-	-	-
76-59	Albert R valley (Park Ranges)	12.32	13.68	1.36	35	48	17	limestone, dolomite
18	Purcell Mtns	19.61	23.09	3.48	2	76	22	siltone, argillite, mudstone
35	Purcell Mtns	17.08	17.94	0.86	35	54	11	argillite
40	Wycliffe till	17.14	17.24	0.10	37	52	11	argillite
48	Cedrus till	17.73	19.87	2.14	24	57	19	phyllite
68	Flathead R tributary	16.60	21.73	5.13	26	41	33	argillite
75	Elk Valley till	14.51	18.57	4.06	28	56	16	limestone, shale, sandstone
82	Elk Valley till	22.96	23.31	0.35	28	59	13	limestone, shale, sandstone

TABLE C.1 (Cont'd)

Sample Number	Location/ Till Type	Plastic Limit	Liquid Limit	Plasticity Index	Less than 2mm Fraction			Bedrock Geology
					Sand	Silt	Clay	
93	Elk Valley till	24.65	29.40	4.75	27	53	20	limestone, shale, sandstone
97	Alexander Cr (Front Rnge)	20.54	23.93	3.39	-	-	-	shale
3	Wycliffe till	16.76	19.12	2.36	-	-	-	limestone
8 TR	Kootenay Rngs	18.71	21.06	2.35	-	-	-	limestone, phyllite
9 TR	Kootenay Rngs	12.84	16.94	4.10	37	44	19	phyllite, limestone
10 TR	Kootenay Rngs	17.79	20.34	2.55	27	54	19	limestone, phyllite
11 TR	Cedrus till (variation)	17.98	21.16	3.18	37	49	14	phyllite

Appendix D

SEISMOLOGICAL DATA

TABLE D.1:

EARTHQUAKES WITH EPICENTRES IN THE EAST KOOTENAY REGION, 1955 TO 1976[1]

Date	Latitude and Longitude of Epicentre (degrees)		Magnitude
1955 JUL 28	49.75	115.00	2.0
1955 DEC 21	49.40	115.50	2.0
1957 MAY 11	49.20	115.80	3.2
1959 MAY 10	50.40	115.10	3.0
1959 OCT 6	49.60	114.70	2.4
1961 JUL 25	49.60	114.40	3.2
1962 MAR 4	49.25	115.20	3.2
1962 MAR 20	49.63	115.35	2.8
1963 MAR 4	49.60	114.80	2.3
1963 AUG 10	49.58	115.42	2.0
1964 APR 14	49.10	115.60	2.5
1964 APR 28	49.00	115.60	2.8
1966 MAY 29	49.40	114.90	3.5
1966 JUL 5	50.33	114.00	2.9
1968 MAR 14	50.80	115.40	2.9
1968 AUG 15	50.40	114.20	3.3
1971 DEC 24	50.76	114.10	2.1
1972 APR 6	50.14	114.69	3.5
1972 APR 7	50.11	114.78	3.4
1972 APR 23	50.07	114.68	3.2
1973 FEB 4	50.19	114.87	2.9
1973 JUN 22	49.86	114.71	3.0
1974 MAY 23	50.23	114.87	2.9
1976 JUL 30	50.67	114.33	2.3
1976 DEC 20	50.23	115.66	2.4

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[1] Those parts of British Columbia and Alberta that are bounded by 114°W, 116°W, 49°N, and 51°N.

TABLE D.2:

EARTHQUAKES OF INTENSITY II OR GREATER THAT AFFECTED A REFERENCE POINT AT 50°N, 115°W IN THE EAST KOOTENAY REGION BETWEEN 1899 AND 1976

Year	Latitude (degrees)	Longitude (degrees)	Distance	Magnitude (Richter)	Intensity (Mercalli)	Acceleration % gravity
1899	60.00	142.00	2027	8.20	III	0.34
1899	60.00	140.00	1924	7.80	III	0.24
1899	60.00	140.00	1924	8.60	IV	0.54
1900	60.00	142.00	2027	8.20	III	0.34
1904	47.50	124.00	715	6.00	II	0.16
1909	49.00	122.70	566	5.60	II	0.15
1914	49.00	130.00	1086	6.50	II	0.15
1914	44.00	129.00	1250	6.70	II	0.15
1915	48.53	121.43	494	5.50	II	0.16
1917	50.00	128.00	927	6.40	II	0.17
1917	50.00	128.00	927	6.50	II	0.18
1918	51.00	118.00	239	5.00	III	0.27
1918	49.75	126.50	823	7.00	III	0.36
1925	46.00	111.20	526	5.80	II	0.20
1925	46.00	111.50	515	6.70	IV	0.51
1925	49.30	112.50	196	4.30	II	0.18
1926	48.75	128.50	985	6.60	II	0.19
1929	52.80	129.50	1050	7.00	III	0.26
1935	46.60	112.00	438	5.60	II	0.21
1935	46.60	112.00	438	6.20	III	0.39
1935	46.60	112.00	438	6.00	III	0.32
1936	46.00	118.30	507	5.70	II	0.19
1939	49.20	129.90	1075	6.50	II	0.15
1939	47.50	122.40	609	5.70	II	0.15
1942	48.10	116.60	241	5.00	III	0.27
1944	44.70	115.20	589	6.10	III	0.23
1945	44.70	115.40	589	6.00	II	0.21
1945	48.00	114.25	228	5.00	III	0.29
1946	49.76	125.34	740	7.30	IV	0.56
1946	50.00	129.00	998	6.50	II	0.17
1946	48.40	114.40	183	5.00	III	0.40
1947	47.20	113.50	330	5.00	II	0.17
1947	44.80	112.00	620	6.30	III	0.26

TABLE D.2 (Cont'd)

Year	Latitude	Longitude	Distance	Magnitude	Intensity	Acceleration
	(degrees)			(Richter)	(Mercalli)	% gravity
1949	47.20	122.60	639	7.10	IV	0.57
1949	53.75	133.25	1315	8.00	IV	0.51
1950	47.25	113.50	324	5.00	II	0.18
1952	48.00	113.80	238	5.60	IV	0.50
1953	48.00	114.00	233	5.00	III	0.28
1956	51.70	131.40	1163	6.80	II	0.18
1956	51.80	129.20	1013	6.70	II	0.20
1957	47.50	116.00	287	5.00	II	0.21
1958	58.60	137.10	1710	7.90	III	0.32
1959	50.40	115.10	45	3.00	III	0.34
1959	47.50	113.00	314	4.90	II	0.17
1959	44.83	111.08	645	7.10	IV	0.56
1959	45.00	110.50	650	6.50	III	0.30
1959	44.80	110.70	662	6.00	II	0.18
1959	44.88	110.73	653	6.50	III	0.30
1959	44.90	111.63	620	6.00	II	0.20
1961	49.60	114.40	61	3.20	III	0.28
1962	49.25	115.20	84	3.20	II	0.19
1962	48.40	113.90	194	4.30	II	0.18
1964	47.90	113.80	249	5.00	III	0.26
1965	49.70	117.40	175	4.00	II	0.15
1965	48.60	116.90	207	4.30	II	0.16
1965	47.40	122.30	608	6.50	III	0.33
1966	51.50	116.50	197	4.50	III	0.22
1966	49.40	114.90	67	3.50	III	0.34
1967	48.40	113.70	201	4.30	II	0.17
1968	50.40	114.20	72	3.30	III	0.26
1969	48.01	114.14	229	4.70	II	0.21
1969	48.04	114.34	223	4.50	II	0.18
1969	47.96	114.20	234	4.40	II	0.15
1970	51.74	131.00	1136	7.00	III	0.23
1972	50.14	114.69	27	3.50	IV	1.00
1972	50.11	114.78	19	3.40	V	1.18
1972	50.07	114.68	24	3.20	IV	0.82
1972	56.77	135.91	1568	7.60	III	0.27
1973	48.91	114.80	122	3.50	II	0.15
1973	49.86	114.71	26	3.00	IV	0.63
1974	48.72	114.89	142	3.70	II	0.15
1975	48.20	114.28	206	4.30	II	0.17
1976	49.02	128.67	991	6.70	II	0.21

TABLE D.3:

SCALE OF EARTHOUAKE INTENSITIES: MERCALLI SCALE MODIFIED AFTER HOLMES (1965) AND UNITED STATES GEOLOGICAL SURVEY (1974)

Intensity (Mercalli)	Characteristic Effects
I	Instrumental: detected only by seismographs
II	Feeble: felt only by a few persons at rest, especially on upper floors of buildings; delicately suspended objects may swing.
III	Slight: felt quite noticeably indoors, especially on upper floors of buildings; like vibrations of passing truck.
IV	Moderate: felt by people while walking; rocking of loose objects, including standing vehicles.
V	Rather strong: felt generally; most sleepers awakened and bells ring.
VI	Strong: trees sway and all suspended objects swing; damage by overturning and falling of loose objects.
VII	Very strong: general alarm; walls crack; plaster falls.
VIII	Destructive: car drivers seriously disturbed; masonry fissured; chimneys fall; poorly constructed buildings damaged.
IX	Ruinous: some houses collapse where ground begins to crack, and pipes break open.
X	Disastrous: ground cracks badly; many buildings destroyed and railway lines bent; landslides on steep slopes.
XI	Very disastrous: few buildings remain standing; bridges destroyed; all services (railways, pipes and cables) out of action; great landslides and floods.
XII	Catastrophic: total destruction; objects thrown into air; ground rises and falls in waves.

Appendix E

CORRELATION BETWEEN TERRAIN UNITS AND SOIL ASSOCIATION COMPONENTS

Note: Soil associations are designated by capital letters, e.g., FL, MK; soil association components are designated by letters plus number, e.g., MD_3, K_7.

M Morainal Materials (Till)

Wycliffe till

$M	$P_{1,3,9,10,11}$; $WY_{1,2,4}$; $K_{1,2,3}$; $MD_{1,2,3,4}$; $FL_{1,2,3,4}$.
$Mv	P_5; WY_5; K_5; MD_5; FL_5.
$M-F sM-A	P_7; WY_7; K_7; MD_7; FL_7.

Cedrus till

$M	$CD_{1,2,3,4}$; $ME_{1,2,3,4}$; $MW_{1,2,3,4}$.
$Mv	CD_5; ME_5; MW_5.
$M-F $M-A	CD_7; $ME_{7,8}$; $MW_{7,8}$.

Elk Valley (Hosmer) till

c$M	$CO_{1,2,3,4}$; $MO_{1,2,3,4}$; $ML_{1,2,3,4}$.
c$Mv	CO_5; MO_5; ML_5.
c$M-F c$M-A	CO_7; $MO_{7,8}$; $ML_{7,8}$.

Elk Valley (Cokato) till

c$M	$CO_{1,2,3,4}$.
c$Mv	CO_5; MO_5; ML_5.
c$M-F c$M-A	CO_7; $MO_{7,8}$; $ML_{7,8}$.

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[1] Appendix E prepared by L. Lacelle, Soils Unit, Terrestrial Studies Branch

[2] Descriptions of East Kootenay soil associations and their components are given in Assessment and Planning Division Bulletin "Biophysical Resources of the East Kootenay Area: Soils". Soil associations are based primarily upon type of surficial material and forest subzonation. Soil association components are defined according to depth of materials, drainage characteristics and geological hazards. Interpretations of soil association components for various types of land use are also given in this soils bulletin.

Other Tills in Elk Valley

\$Mb	$MZ_{1,2,3,4}$; $MT_{1,2,3,4}$; $MG_{1,2,3,4}$.
\$Mv	MZ_{5}; MT_{5}; MG_{5}.
\$Mb-F	MZ_{7}; $MT_{7,8}$; $MG_{7,8}$.
\$Mb-A	

Flathead Till

Mum	$MM_{1,2,3,4,}$; $MT_{1,2,3,4}$; $MU_{1,2,3,4}$; $MO_{1,2,3,4}$; $MN_{1,2,3,4}$; $ML_{1,2,3,4}$.
Mv	MM_{5}; MT_{5}; MU_{5}; MO_{5}; MN_{5}; ML_{5}.
Mb-F	$MM_{7,8}$; $MT_{7,8}$; $MU_{7,8}$; $MO_{7,8}$; $MN_{7,8}$; $ML_{7,8}$.
Mb-A	

Purcell Tills

sMb	$SL_{1,2,3,4}$.
sMv	SL_{5}.
sMb-F	$SL_{7,8}$.
sMb-A	
\$Mb	$MS_{1,2,3,4}$; $SY_{1,2,3,4,9}$; $SS_{1,2,3,4}$; $SN_{1,2,3,4}$.
\$Mv	MS_{5}; SY_{5}; SS_{5}; SN_{5}.
\$Mb-F	MS_{7}; $SY_{7,8}$; $SS_{7,8}$; $SN_{7,8}$.
\$Mb-A	

Tills on Limestone in Rocky Mountains

\$Mb	$MD_{1,2,3,4}$; $FL_{1,2,3,4,}$; $SP_{1,2,3,4}$; $MM_{1,2,3,4}$; $MC_{1,2,3,4}$; $MX_{1,2,3,4}$; $MP_{1,2,3,4}$.
\$Mv	MD_{5}; FL_{5}; SP_{5}; MM_{5}; MC_{5}; MX_{5}; MP_{5}.
\$Mb-F	MD_{7}; FL_{7}; $SP_{7,8}$; $MM_{7,8}$; $ML_{7,8}$; $MX_{7,8}$; $MC_{7,8}$; $MP_{7,8}$.
\$Mb-A	

Tills on Sandstone

sMb	$MF_{1,2,3,4}$; $MU_{1,2,3,4}$; $MN_{1,2,3,4}$.
sMv	MF_{5}; MU_{5}; MN_{5}.
sMb-F	MF_{7}; $MU_{7,8}$; $MN_{7,8}$.
sMb-A	

Tills on Red and Green Mudstones

c\$Mb	$MK_{1,2,3,4}$; $MR_{1,2,3,4}$.
c\$Mv	MK_{5}; MR_{5}.
c\$Mb-F	$MK_{7,8}$; $MR_{7,8}$.
c\$Mb-A	

F Fluvial Materials

Floodplains

$F^{A}l$ Fl	GN_{10}; FR_{10}; $AS_{1,3,9,10,11,12}$; FT_{10}; $KO_{10,11}$; $L_{10,11}$; $FS_{1,3,10,11}$; MA_{10}; $FF_{1,3,10,11}$; $CN_{1,3,10,11}$; $FU_{1,3,10,11}$; $FZ_{1,3,10,11}$; $FA_{1,3,10,11}$; $FD_{1,3,10,11}$; $FV_{1,2,10,11}$; $FE_{1,2,10,11}$; $FK_{1,2,10,11}$; $FJ_{1,2,10,11}$.
$\$F^{A}l$ $\$Fl$	$S_{1,2,3,10,11}$; $NW_{1,2,3,11}$; $FM_{1,3,9,10,11}$; $FQ_{1,2,10,11}$.

River Terraces, Glacial Outwash and Ice-contact Deposits

Ft $F^{G}l$	$GN_{1,2,3,4,10}$; $KR_{1,2,3,4}$; $GY_{1,2,3,4}$; $KA_{1,2,3,4}$; $SA_{1,3,9,10,11}$; $H_{1,3,7}$; $E_{1,2,4,7,9}$; $KY_{1,2,4,9}$; $FX_{1,2,7,9}$; $F_{1,2,9}$; $KO_{1,2,3,4}$; $L_{1,2,3}$; $KE_{1,2,3,4}$; $MY_{1,2,3,4}$; $GR_{1,2,3,4}$; $GB_{1,2,3,4}$; $GD_{1,2,3,4}$; $GT_{1,2,3,4}$; $KG_{1,2,3,4}$; $GC_{1,2,3,4}$; $GL_{1,2,3,4}$.
Ft-A	KE_{7}; MY_{7}; GR_{7}; $GB_{7,8}$; $GD_{7,8}$; $GT_{7,8}$; $KG_{7,8}$; $GC_{7,8}$; $GL_{7,8}$; $GY_{7,8}$; $KA_{7,8}$; $KR_{7,8}$.

Fluvial Fans

Ff	$FR_{1,2,3,4,7}$; $FT_{1,2,3}$; $SA_{1,3,9,10,11}$; $H_{1,3,7,9}$; $E_{1,2,4,9}$; $FX_{1,2,9}$: $F_{1,2,9}$; $KO_{1,2,3,4}$; $L_{1,2,3}$: $CA_{1,2,3,4}$; $MA_{1,2,3}$; $GB_{1,2,3,4}$: $GD_{1,2,3,4}$: $GT_{1,2,3,4}$; $FO_{1,2,3,4,9}$; $FP_{1,2,3,4}$; $KG_{1,2,3,4}$; $GC_{1,2,3,4}$; $GL_{1,2,3,4}$; $GZ_{1,2,3,4,9}$; $GE_{1,2,3,4}$.
$F^{A}f$	$FR_{7,8,10}$; $FT_{7,8,10}$; $KE_{7,8}$; $MY_{7,8}$; $GR_{7,8}$: CA_{7}; $MA_{7,10}$; $GB_{7,8,9}$; $KO_{10,11}$; $L_{10,11}$.
$Ff\text{-}E^{A}$ Ff-A	$GD_{7,8}$; $GT_{7,8}$; $FO_{7,8}$; $FP_{7,8}$; $KG_{7,8}$: $GC_{7,8}$; $GL_{7,8}$; $GZ_{7,8}$; $GE_{7,8}$.

L, L^{G} Lacustrine and Glaciolacustrine Materials

Lt Ll Lu $L^{G}hu$	$LY_{1,2,3,4}$; $M_{1,2,4,10}$; $AZ_{1,2,3}$; $LN_{1,2,3,4}$; $LL_{1,2,3,4}$.
Ls-F Lt-V Lt-P	LY_{7}; M_{7}; AZ_{7}; LN_{7}; LL_{7}.

C Colluvial Materials

Cb Ca	$CLD_{1,2,3,4}$; $CE_{1,2,3,4}$; $CL_{1,2,3,4,}$; $CP_{1,2,3,4}$; $CH_{1,2,3,4}$; $CF_{1,3}$; $COL_{1,2,4}$; $CR_{1,2,3,4}$; $COR_{1,2,3,4}$; $CG_{1,2,3}$; $CC_{1,2,3,4}$; $CAI_{1,2,3,4}$; $CK_{1,3,4}$; $CW_{1,2,3,4}$; $CU_{1,2,3,4}$; $CB_{1,2,3,4}$; $CX_{1,2,3,4}$; $CJ_{1,2,3,4}$; $CT_{1,2,3,4}$; $CM_{1,2,3,4}$; $CQ_{1,2,3,4}$; $CI_{1,2,3,4}$; $CS_{1,2,3,4,9}$; $CY_{1,2,3,4,9}$; $CZ_{1,2,3,4,9}$; $COY_{1,2,3,4,9,10}$.

C Colluvial Materials (CONT'D)

Cb-A Cf-A Cf Cb-F	CLD_7; $CE_{7,8}$; $CL_{7,8}$; $CP_{7,8}$; $CH_{7,8}$; COL_7; CR_7; COR_7; CG_7; CC_7; CAI_7; CK_7; $CW_{7,8}$; $CU_{7,8}$; $CB_{7,8}$; $CX_{7,8}$; $CJ_{7,8}$; $CT_{7,8}$; $CM_{7,8}$; $CO_{7,8}$; $CI_{7,8}$; $CS_{7,8}$; $CY_{7,8}$; $CZ_{7,8}$; $COY_{7,8}$.
rCba blockfields rock glaciers	$YR_{1,9}$; $YK_{1,9,10,11}$.
Cv	$RY_{1,2,3,4,5,6}$; $BH_{1,2,3,4,5,6}$; $RC_{1,2,3,4,5,6}$; $RS_{1,2,3,4,5,6}$; $RD_{1,2,3,4,5,6}$; $RH_{1,2,3,4,5,6}$; $RF_{1,2,3,4,5,6}$; $RG_{1,2,3,4,5,6}$; $BN_{1,2,3,4,5,6}$; $BO_{1,2,3,4,5,6}$; $RB_{1,2,3,4,5,6}$; $RP_{1,2,3,4,5,6}$; $RI_{1,2,3,4,5,6}$; $BB_{1,2,3,4,5,6}$; $RU_{1,2,3,4,5,6}$; $BP_{1,2,3,4,5,6}$; $RK_{1,2,3,4,5,6}$; $BK_{1,2,3,4,5,6}$; $BC_{1,2,3,4,5,6}$; $BF_{1,2,3,4,5,6}$; $RE_{1,2,3,4,5,6}$; $BS_{1,2,3,4,5,6}$; $RR_{1,2,3,4,5,6}$; $RT_{1,2,3,4,5,6}$; $RN_{1,2,3,4,5,6}$; $RA_{1,2,3,5,6,9,10}$; $RJ_{1,2,3,5,6}$.
Cv-F Cv-A	RY_7; $BN_{7,8}$; $BK_{7,8}$, $BH_{7,8}$; $BO_{7,8}$; $BC_{7,8}$; RB_7; BF_7; RC_7; RP_7; RE_7; RS_7; RI_7; $BS_{7,8}$; $RD_{7,8}$; $BB_{7,8}$; $RR_{7,8}$; $RH_{7,8}$; $RU_{7,8}$; $RJ_{7,8}$; $RT_{7,8}$; $RF_{7,8}$; $BP_{7,8}$; $RN_{7,8}$; $RG_{7,8}$; $RK_{7,8}$; $RA_{7,8}$.

E Eolian Materials

sEu sEm	$F_{1,2,9}$.
Ev Eb	$KY_{1,2,4,9}$.

R Bedrock

Rs	RO

O Organic Materials

Ol Ov Ob	$OL_{1,11}$; $OS_{1,11}$; $ON_{1,9,11}$; $OD_{1,10,11}$.

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